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CONGRESSIONAL WORKSHOP ON ADVANCED MATERIALS RESEARCH AND DEVELOPMENT

REPORT

TO THE

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LETTER OF TRANSMITTAL

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
Washington, D.C., April 22, 1985.

To All Members, Committee on Science and Technology:

On January 15, 1985, with the help of the Office of Technology Assessment, the Committee sponsored a Congressional workshop on advanced materials research and development. The purpose of the workshop was to provide a clearer definition of the issues requiring reveiw in evaluating the implementation of the National Critical Materials Act of 1984 (P.L. 98-373, Title II). In particular, the workshop focused on the parameters necessary to define a national, Federal advanced materials research plan as called for in the Act. Specifically, the workshop considered the following areas related to materials R&D infrastructure: (1) Materials Research Facilities; (2) Materials Engineering and Science; and (3) Research Establishment.

Participants consisted of seventeen experts, almost equally divided between academia and industry. In addition, more than twenty representatives from the various Federal agencies or departments with major materials R&D programs participated as observers. It is our hope that this report, with recommendations and conclusions drawn from analysis of the workshop discussion, will be a valuable resource for the Committee in its future actions on this matter.

I commend this report to your attention.

Sincerely,

DON FUQUA, *Chairman.*

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EXECUTIVE SUMMARY

On January 15, 1985, a workshop was held on materials research and development sponsored by the House Committee on Science and Technology. Over forty representatives from industry, academia and the Federal government were selected to participate in the workshop. The workshop was to provide assistance to the Committee in carrying out its oversight responsibility with respect to the "National Critical Materials Act of 1984" relating to advanced materials research and development.

In particular, the workshop focused on the parameters necessary to define a national Federal advanced materials program plan. While broader issues were considered, discussion focused on three areas related to the materials R&D infrastructure: (1) Materials Research Facilities; (2) Materials Engineering and Science; and (3) Research Establishments.

Conclusions and Recommendations - The following conclusions and recommendations stand out in analysis of the workshop discussion.

- There is a strong need to demonstrate the national importance of materials R&D and to set research priorities through a comprehensive analysis of materials research and technology goals.
- Priority setting for materials research and technology requires involving a sufficient balance among all participants in the materials research community.
- Priority and goal setting should focus on both the customer for and producer of materials research.

- One area specifically noted as needing further attention as a priority is advanced materials processing.
- The interface between materials design, materials processing and manufacturing must be bridged to enable U. S. industry to move quickly to introduce advanced materials into components and systems.
- Networks linking industry, academia and the Federal laboratories in joint efforts should be used where appropriate to insure that priorities as well as wise allocation of resources are considered.
- Congress should continue to focus on overall materials R&D policy, but should refrain from being too involved in the technical details of programs once approved.
- A national program plan must focus on the long term.

WORKSHOP ANALYSIS

Introduction

Materials, once defined by Dr. Frank Huddle, of the Congressional Research Service of the Library of Congress, as "the stuff from which we make things", is fundamental to our society and its needs, underlying almost entirely our national industrial capability. As such, the understanding of old and new materials, their availability, their synthesis and their use remain vital to our nation's economic health as well as national security. Congress, over the past decade or more has grown increasingly aware of this importance and has passed a number of laws designed to provide for a comprehensive national materials policy. Most recently enacted and signed into law was the "National Critical Materials Act of 1984" (P.L. 98-373). A major provision of that act (Section 205(a)) calls for the establishment of "a national Federal program plan for advanced materials research and development."

In order to assist the Committee on Science and Technology in carrying out its oversight responsibilities of the law and in particular the provision relating to advanced materials research and development, this Congressional workshop on advanced materials R&D was held. The purpose of the workshop was to provide a clearer definition of the issues requiring review in evaluating the implementation of the materials act. In particular the workshop focused on the parameters necessary to define a national, Federal advanced materials program plan.

While broader, cross cutting issues were considered, discussion was focused on three areas related to the materials R&D infrastructure: (1) Materials Research Facilities; (2) Materials Engineering and Science; and (3) Research Establishments.

Participants, selected with the help of the Office of Technology Assessment, consisted of seventeen representatives, almost equally divided between industry and academia. In addition to Congressional staff and others, representatives from each of the Federal agencies or departments with major materials R&D programs attended as observers. Appendix A shows a complete listing of those attending and participating in the workshop.

Definition of Materials Research and Development

Confusion in defining materials research and development and its purposes appears to lie at the heart of much of the debate related to national materials research policy and the establishment of priorities for such research. In order to maintain a frame of reference for the ensuing workshop discussion, the participants focused on this definitional question. Dr. Dean Eastman, in the opening presentation offered the following statement related to defining materials research.

> "Materials research (science and technology) deals with the diverse properties of solids, liquids and their interfaces. It is interdisciplinary, involving materials science, including metallurgy, ceramics, polymers, major sub-areas of physics and chemistry; as well as special subareas of earth sciences, biology and medicine".

In criticizing the lack of emphasis in this definition on those aspects of materials related to engineering and applications, it was suggested that a better balance might be reflected by the COSMAT statement (Materials and Man's Needs: Materials Science and Engineering; National Academy of Sciences, 1974) that:

> "Materials science and engineering is concerned with the generation and application of knowledge relating the composition, structure, and processing of materials to their properties and uses."

In following with this, general consensus agreed with the statement that: materials research is the process for developing knowledge of the inter-relationship between structure, properties and processing. *

* (One reviewer suggested yet another definition taken from the Interagency Committee on Materials [COMAT] 1983 report on Federal materials research and technology -- see appendix C)

This statement holds whether we are discussing atomic structure, molecular, structural levels or macro-bulk-property and structural levels.

Establishing Priorities

The first point raised in the opening discussion was the need to set priorities for materials R&D before any decision related to facilities, balance of scientific and engineering activities or institutional mechanisms could be evaluated. Strong consensus existed that this should be the first and continuing order of business for any national program planning processes.

Having stated this, it was not clear from the ensuing discussion what were the best detailed procedures for establishing such priorities. All were in agreement that Congress should focus on broad policy setting while leaving the establishment of priorities to the Executive branch and the materials community at large. However, such priority setting as now exists within the Executive branch is not considered perfect.* For instance it was noted that members of the Seitz/Eastman Committee on large, materials research facilities were uneasy about establishing priorities in one narrowly defined materials approach (large facility) to the exclusion of all

* Some federal agencies have extensive review and priority setting apparatus, notably the Energy Research Advisory Board (ERAD) and Energy Materials Coordinating Committee (EMACC) of DOE. Other, such as NASA, DOD, DOI, and DOC are considerably less developed.

others (medium and small facilities/research). The Seitz/Eastman Committee recommended that additional panels were necessary to establish a more balanced approach. As noted in Dr. Eastman's presentation "general policy (strategies/goals) for the various performers -- Federal, university, industry -- need to be established in response to identified national priorities."

One difficulty in establishing priorities lies in determining how far reaching and detailed such priorities should be. For instance some suggested at the workshop that any follow-up to the Seitz/Eastman report and, in particular, any recommendations should be limited solely to basic materials research as defined by DOD's 6.1 research or NSF's materials science programs. Others disagreed, suggesting that a "quagmire" existed at both ends of the materials R&D spectrum created by focusing too heavily on "applied" materials research on one hand or too heavily on "basic" materials research on the other. As pointed out in later discussion, materials research by its very nature can not be easily categorized by such terms as "basic" or "applied". Industries conducting advanced composites research, for example, have almost entirely eliminated any "barriers" between laboratory design and product development. The two go hand in hand.

Any decision to establish long-term priorities in materials research will thus obviously require a balanced assessment including representatives of the major segments of the materials community, i.e. materials science and engineering, "applied" as well as "basic" research; industry;

academia and government; large and small business needs; basic materials industry and new, high-tech materials industry. Thus, the "customer" as much as the "product" should determine the final priorities in materials research needs. The National Council on Critical Materials called for in the 1984 Act, working closely with the materials community, could be seen as one possible, but not unique means for ensuring a balanced assessment.

The Need for Facilities

The presentation by Dr. Eastman stated that three major elements were needed in any national Federal materials R&D program. First, a policy -- presumably for establishing goals and priorities -- for the immediate and long term is necessary. Second, a review mechanism is required. This mechanism should establish the interrelations between the various participants, as well as an assessment of the needs of each sector. Third, the program requires continuing Federal coordination and implementation which considers many factors. These factors include: time scale, international programs, personnel, facilities, and technology transfer. Thus, related to facilities, Eastman determined (1) that a diverse spectrum of approaches and facilities is required for effectiveness and (2) the level and balance of facilities should be determined by establishing priorities for the entire program and between the various sub-areas and participants.

The question of priority setting already discussed above was amplified by the comments and discussion related to facilities. Facilities are

simply a means to an end. In terms of the research objectives, it is not important to ask if the facilities are large, medium or small (or expensive, of intermediate costs or inexpensive). The proper concerns are: for what purpose will the facilities be used? who are the customers? what is the product or goals? Thus, any research program (or programs) should be "scenario and strategy" driven with facilities being only a part of the process (in examining these statements, one reviewer noted that scientific justific tions of most facilities exist, if only people would read them; another noted that it makes a great deal of difference to the policy process whether a facility is large or small, cheap or expensive).

There are exceptions to this concept. For instance, it was pointed out that highly detailed goals or missions are not appropriate for basic research but are indispensible when considering questions of national defense. This idea certainly follows in line with general policy related to the Office of Science and Technology Policy's and the National Science Foundation's charge to foster the overall health of science and engineering. Thus priority setting for facilities that will conduct primarily fundamental research activities need not be justified necessarily on other grounds. In fact it is more damaging to create artificial justifications related to economic wellbeing or other unsupported goals when the main thrust is really to simply enhance scientific understanding.

The study of materials, unfortunately, often blurs the distinction between application and fundamental research. That is in fact one of it's greatest attractions -- fundamental discoveries in materials often lead to major technological breakthroughs of enormous proportions; e.g., the invention of the transitor and the beginning of modern microelectronics, computers and communication. The reverse is also true. Technological needs, such as those in advanced microchip design, have driven entire areas of fundamental research of materials' properties at submicron levels. Because fundamental materials research may lie in such close proximity to actual use and vice versa, the question of balance between "a diverse spectrum of approaches and facilities" (as suggested by Eastman) seems all the more important.

Discussion also revolved around questions of what constituted a "facility". Does a facility most properly constitute a single major piece of equipment, e.g. a cold neutron device, or does a conglomeration of smaller research elements with a commonality of research goal (or goals) such as materials processing - qualify? While such definitional questions may seem trivial, their resolution are essential to allowing policy and priority setting to occur in an even-handed manner. As clearly pointed out in the discussion however, what is important is the quality of researchers themselves and the manner in which they interact, not the research equipment.

Finally, the question of existing versus new materials facilities was raised. The Seitz/Eastman Committee concluded that it is essential that

priorities consider the development of new capabilities at existing large facilities - this to occur over the next decade, as well as major new facilities to be constructed in the next decade (design and planning to be started now). As one participant observed, no materials research in his experience had ever been held up because of the lack of new facilities. Rather the lack of completion of existing facilities such that they were not fully operational had led to research delays or discontinuities. Thus, any resource allocation and priority setting must allow for completion and full equiping and/or refurbishment of existing major facilities before committing actual construction monies for new ones.

Materials Research and Development - Engineering and Science

The workshop raised a number of questions related to materials engineering and materials science. Is there proper balance? What is the criteria for evaluating this balance? How does this balance relate to the development of interdisciplinary research? In addressing these questions it was not intended to pit one element (science) against the other (engineering) but rather to look at the contributions and needs from the perspective of each.

The presentation by Dr. George Dieter underscored this when he noted that materials research is best when science and engineering are intimate enough so that the distinction becomes difficult. However, some data would indicate that within the university environment, barriers, artificial

or otherwise, exist, preventing healthy development of materials engineering as compared to materials science. Dieter suggested a number of reasons for this lack: unavailability or difficulty of dependable funding; concern about peer evaluation, if not peer esteem; lack of equipment; the need for an interdisciplinary approach; the often needed, close coupling with industry and the problems this coupling can create within the university environment.

Whereas ensuing discussion was not in complete agreement with Dr. Dieter a number of important points were brought out. Materials engineering, while not developing as a discipline, was advancing through growth in other engineering fields. Electronics was one example cited. As such materials engineering was advancing through efforts at the interface of other engineering disciplines. Another point made was that at least in some areas, the barriers Dr. Dieter alluded to were falling, particularly in industry. Polymeric composites research was noted as a good example. Within the university community, however, "deep seated cultural barriers" still existed regarding interdisciplinary materials research such as manufacturing processes. Obviously increased funding support could cause an emphasis in such areas if such policy and priority were clearly identified.

Central to this discussion was the focus on materials processing. Despite the expressed interest over the past several years, Federal programs, as well as other private sector activities, have not adequately renewed within the university what was once integral to hands-on education and research in materials engineering. Earlier discussion pointed to the need for focussing on materials processing through a few, large integrated facilities or more broadly disseminated facilities and programs. By focusing in this manner on the interface between the structure of materials, their properties and processing, an enormous opportunity exists for advances in materials R&D and its applications. Because of the generic nature of much of this research, the industrial sector is not prepared to pursue such research without substantial "up-front" funding by the Federal government.* On the university side, lack of processing research support has shifted their efforts away from processing and synthesis toward analysis and characteristization of materials, creating a substantial gap in materials research.

* There is not total agreement to this statement. One reviewer noted that "Materials processing is the area where industry generally does pursue, as it has a major impact on profits. The universities have hardly contributed to the field of materials processing. These statements are particularly true of the electronic materials."

Finally, Dr. Dieter noted that materials engineering is not taking advantage of modern technological changes such as computerized design and manufacturing as found in other engineering disciplines. Our failure to bring these ideas into the materials engineering curriculum through courses or research does not adequately prepare our young engineers. It is assumed that industry will pick up the slack, but it is not clear that it is capable of doing so, certainly not in any comprehensive way. Again the integration of materials structure and properties to processing using modern technological advances (computer design, modeling, etc.) appear to point the way to substantial opportunities in materials research.

Research Establishments

Institutional mechanisms for conducting materials research follow many diverse models, some based solely on Federal support (e.g. national Federal laboratory facilities), some with primarily state or private sector support (state university departments and/or others in combination). Dr. Thomas Moss in his presentation noted the importance of being flexible and creative in providing institutional mechanisms to support materials research. The important objective is to be task oriented and to seek out the right people or research group to carry out the task. One means of more effectively managing research is through the use of networks that link industry, the universities and the national laboratories in joint efforts. Obviously setting goals and priorities is key to any effort.

Unfortunately, as noted by Dr. Moss, there is evidence that the materials R&D program is not placing enough emphasis on setting goals or priorities, but is instead more interested in "slicing up the pie" -- that is, allocating the limited funding resources that exist for parochial interests.

Networking is one means of insuring that both priorities, as well as wise allocation of scarce resources, are considered. Industry is not likely to put money into efforts that it cannot legitimately justify. The university community will have difficulty in obtaining support unless its activities correspond to priorities of its customers, either industry or the government or both. Limited Federal dollars are more likely to go to those programs in which cost-sharing will multiply any Federal effort.

In comparing the private sector versus Federal efforts it seems probable that the two activities will complement each other (The Committee on Materials studies show a roughly 4 to 1 ratio of industry to Federal materials R&D). The Federal government is perhaps best at seeing the "forest", whereas the states and industry focus best on the "trees". Both are necessary and both are important. Thus, any program plan must be structured to provide for a balance on the two approaches.

Setting research goals and establishing a research balance obviously determines the kind of institutional mechanism thought most appropriate. The suggestion that a "natural order of balance" existed through the peer review system was countered by the view that the present system tends to

exclude the smaller businesses where a large portion of the more creative elements of the materials research community can be found. Congressional hearings in the past several years have indicated that small businesses are strongly dependent on new innovative technologies whereas large industry interests tend to more conservative and often less innovative technologies (one reviewer noted that some small business innovation occurred through exploitation by ex-employees from large companies of new ideas originally developed in the parent company). Research priorities established by one element could favor extension of past research over "truly new ideas". The same arguments can be applied in the academic community. Thus, any "natural order" is really defined by a potential bias built into the system. Establishing priorities will require great care that all relevant groups are represented and considered.

Other Questions

As can be seen in the above analysis and discussion it is difficult, if not impossible, to separate clearly the three agenda items selected for the workshop. Discussion of facilities, requires an understanding of the scientific and social priorities, which in turn must encompass the proper balancing between engineering and materials science. The type of institutional establishments or mechanisms, whether university-industry in character, multidisciplinary or cost-sharing with Federal monies is determined in large part on the goals, priorities and existing physical facilities already in existence. Thus any national program plan must seek an integration of these essential issues.

In addition to the three main agenda items, other thoughts were put forward as important to any strategy or national Federal program plan for advanced materials research. Education and training were touched upon in the workshop discussion. Most were in agreement that research education, particularly in materials science was best handled within the university system. As well, industry was viewed as best focusing on the training of those involved with specific industrial needs. Once said, however, a number of concerns surfaced regarding these roles: Does the university education provide a sufficient basis for industry needs? Is industry taking on more of a role in training materials specialists, particularly at the baccalaureate level? Is industrial training too narrowly defined for the long-term, overall needs of materials specialists? What facilities provide the best training for materials research specialists, and in what areas? Can we ascertain that we are educating and training the right number of individuals to meet future needs in advanced materials. How can we ascertain the quality of that education or training?

Another issue related to the question of setting goals and determining when goals, once set were achieved. It was noted that it is easier to set technical goals than scientific or research goals and that assessing the entire field of materials would be extremely difficult to carry out. Whatever assessments are made would better focus on specific sub-areas. Measuring progress in meeting goals was also raised. Congress is probably <u>least</u> capable of measuring such progress, and sophisticated analysis should best be left to Federal program managers. This view, however,

ignores the oversight and policy setting responsibility mandated to Congress, and thus some kind of Congressional interaction, perhaps, involving such groups as the Office of Technology Assessment or the National Academy of Science and Engineering would have to be sought.

Conclusion and Recommendations

The following conclusions and recommendations stand out in analyzing the workshop discussion:

-- There is a strong need to dramatize the general national needs for materials R&D and to set research priorities through a comprehensive analysis of materials research and technology goals.

-- Whereas it is not entirely clear as to the most acceptable mechanism (the National Critical Materials Council, and/or OSTP, and/or the Academies of Science and Engineering, or a combination of groups), it was clear that the effort must provide for sufficient balance among industry and academia, engineering and science; large, medium and small institutional facilities; large industry and small business needs; and federal and private sector needs.

-- Recommendations relating to priorities or goal setting should clearly focus on the "customer" as well as the "product", taking account of historical patterns of work in the U.S. and international trends affecting us in the future.

-- One area specifically noted as needing further attention as a priority is advanced materials processing. This is one example where engineering views require further emphasis.

-- The interface between materials design, materials processing and manufacturing must be bridged to enable U.S. corporations to more quickly introduce advanced materials into components and systems. This requires radical changes at universities and in the university-industry relationship(s).

-- Networks that link industry, the universities and the national laboratories in joint efforts provide one means for more effective management of research and should be used where appropriate. This insures that priorities as well as wise allocation of resources are considered.

-- Congress should continue to focus attention on the questions of overall policy, but should refrain from being too involved in the technical details of programs once approved through a comprehensive analytical process.

-- Any national program plan must focus on the long term; but as was noted during the workshop, "The long-term is getting shorter all the time".

Materials Research and Development Workshop

Report of the Discussion

A. FACILITIES

The first session opened with a presentation of a paper prepared by Dr. Dean Eastman on materials R&D facilities. (see Appendix B) The major points made in the presentation were the following.

1. A general materials research and development policy is necessary for the program and for each participant -- federal, university, and industry -- in the program.
2. A diverse spectrum of approaches and facilities is required for an effective program.
3. The level and balance of facilities should be determined by first establishing priorities for the national materials R&D program and between the various subareas and participants.

There are three important aspects of an effective materials R&D program as pointed out in the paper. First, a policy -- for the immediate term and the long term -- is needed. Second, a review mechanism is required. This mechanism should establish the connections between the various participants in the materials R&D program, and an assessment of needs. Third, the program requires Federal coordination and implementation which considers many factors. These include timescale, international programs, personnel, facilities, and technology transfer. In carrying out a materials R&D program it is important to focus on the customer(s).

Setting Priorities: Following the presentation, the workshop was opened for discussion. The first point raised was the need to set priorities for materials R&D before it could be determined which facilities should be supported and built in this country. It was stated that the programs must be "scenario and startegy driven." Facilities are a means to that end. Another participant stated that the classification of large, medium and small was improper. The questions to ask were first, what they are going to be used for and then to determine the size. A comment was added that the quality of the facilities was more import than quantity.

It was next pointed out by a participant that in some cases it is allright to develop tools without goals while in other cases that was not possible. For example, he said, national goals are not needed for basic research but are indispensible for national defense. He asserted that materials R&D may be somewhere in the middle, although closer to the goal oriented than tool oriented definition. Another participant stated that one should ask what the materials R&D "practictioner" will work on. He asked how important is a $200 million facility to the next 15-20 years of materials engineering and science compared to a smaller facility? It was pointed out, however, that new, major facilities would not be in operation for 10 to 15 years. What is needed now, according to this participant, is to start planning for the research needs of the next decade now so that we can decide which facilities to begin.

Toward the specific issue of balance among facilities, one participant agreed that the points raised by the background paper needed addressing if the proper balance was to be set. Another asserted that large facilities provided

a training ground for personnel but it was also stated that such a justification, by itself, was not sufficient. A participant then added that large facilities could not be justified on the basis of materials R&D alone, but that they were broader, scientific tools.

A discussion also took place concerning the process for making decisions about facilities. One participant asserted that the decision making bureaucracy is already in place and that a comprehensive view is being carried out by that bureaucracy. Others disputed this claim and stated that the bureaucracy was too detailed and not undertaking this comprehensive overview. Another stated that the questions to be answered before making the decisions haved been identified, which is a major step, but the process of answering them still needed to be carried out. A participant added that he felt that the advice from existing materials groups to the decision process was not being adequately implemented.

Analysis of Materials R&D Needs: A second point raised by the workshop concerned the need to carry out a comprehensive analysis of materials R&D needs as part of the priority setting process. This study would be a follow-on to the Seitz report and should examine other kinds and sizes of facilities. In particular, processing facilities were mentioned by one participant. Another mentioned the upcoming study by the National Academy of Science which will focus on basic materials research. This would be a follow-on to the Seitz study and will meet part of the requirement to broaden the analysis to a materials R&D needs assessment. A cautionary note was raised that there are "quagmires" at both ends of the materials R&D spectrum in that an analysis can focus too heavily on applied or too heavily on basic research. Therefore any needs assessment must be careful not to fall into this "quagmire". In

response to a particular question about the ability of a Council of Critical Materials to set priorities, one participant stated that he thought it could, but reiterated that a thorough, comprehensive study of materials R&D was needed.

With particular reference to the Seitz report, one participant, who also served on the Seitz panel, pointed out that they felt very constrained and were not able to deal effectively with the vast majority of materials R&D facilities needs. Another workshop participant added that he believed that the need for facilities and instrumentation at the one million dollar level was very great, but that those needs could not be addressed in a technically informed way without a follow-on assessment.

Engineering Input: A third point raised by some participants was the apparent lack of engineering input to the materials R&D program. In particular they asserted that the interface between engineering and science needs to be stressed. One participant claimed that the "absence" of engineering sciences in materials R&D planning was a big oversight, and this separation inhibits the expansion of materials applications. Another pointed out that much more fundemental work in the science-engineering interface was needed. It was important to do materials engineering in a more rigorous manner. In particular design methodology must be developed before we can intelligently determine how best to use materials R&D facilities. This methologogy calls for the increased use of numerical and computational methods and experimentation. The application of such methods should be part of a broader definition of materials R&D in order to best define priorities. Other participants echoed this assertion, although some felt that there sufficient engineering input already existed, and additional emphasis may skew the

program too far away from the science. In this latter vein, one participant noted that much of materials research cannot carry the support load for physicists, chemists and other scientists and engineers who are doing research relevant to materials but not in any defined materials research areas. While it is clear there is concern about the particapation of engineering disciplines in materials R&D priority setting, there also appears to be significant controversy about the level of that contribution.

Completion of Existing Facilities: Another point was raised in response to a question about how decisions should be made concerning facilities in the absence of completed materials R&D needs assessments and the setting of priorities. One participant stated that in his experience, no materials research was held up because of a lack of new facilities. On the other hand he did know of research being held up because existing facilities were "not fully operational". He urged that funding be assigned to existing facilities before any new ones were started. It was pointed out that this recommendation was also made by the Seitz report, although they also recommended the starting of a few, new facilities, in particular the cold neutron source. In this connection, one participant stated that any decision about funding of major facilities should also consider downstream costs. He did not believe that we were anywhere near such a determination which makes answering the question of balance very difficult at this time.

Materials Processing Facilites: Some of the workshop participants also espressed concern that materials processing facilities were not considered by the Seitz panel. This came in response to a statement made by one participant, who was also on the Seitz panel, that the latter had a very hard time coming up with examples of "other facilities" which could also qualify as

large facilities beyond the synchrotron and neutron sources. Two workshop participants claimed that materials processing facilities -- facilities which allowed research on generic processing technologies and which consisted of an integrated number of relatively small pieces of equipment into a relatively large system -- were missing from consideration. They claimed that their absence "severely handicaped" the advancement of materials R&D. They also stated that these facilities -- which allowed one to examine the interface between the structure of materials, cheir properties and processing -- offered an enormous opportunity for materials R&D and for expanding opportunities of materials applications. Such research may properly be defined as generic research, which would fit into a category of broad, applied research needed for a wide spectrum of specific manufacturing processes.

In response to a question about industrial interest in materials processing facilities, several participants stated that such facilities would not have any trouble obtaining continued industrial support once they were operational. Controversy existed about whether such facilities properly belong on the university campus and whether such facilities should be classified as large in the same sense as a synchrontron or neutron source. One participant asked, "Just how big does a materials processing facility have to be to provide useful results?" He also asked whether it belonged on in the university environment.

In the discussion that followed this proposal about processing facilities, one participant stated that this is an area that a goal can be defined and a program developed to focus in on that goal. He raised the question, however, as to whether the Federal government could intelligently define those goals. While he believes they can he urged that others, such as

the states, be given a role in setting these goals. He suggested that one means of goal setting was to send out requests for proposals and look for areas where you get matching funds from industry. Another participant stated an "opening" up of the area of materials processing to R&D funding so that the the materials community can define the types and sizes of such facilities is all that is needed.

Curriculum Upgrading: It was claimed by another participant that universities have shifted away from processing and synthesis toward analysis and characterization of materials because of a lack of facilities on which to do processing research. Finally, a point was made that it was also important to upgrade the curriculum to integrate the development of knowledge of materials with processing. This upgrading should also carry over to the undergraduate curriculum since a large percentage of the engineers working in industry do not go on to graduate school. The question of materials processing as part of the materials R&D program, and, in particular, the role processing facilities should play in determining the proper balance of materials R&D facilities appears to be important but still far from resolution.

Customer Needs: The final point raised in the first session concerned the importance of "customer" contribution to decisions about facilities and the determination of priorities. It was pointed out that materials science is a very broad field and materials priorities are defined by each practitioner according to his goals (e.g., weapons systems or energy technology). Therefore the importance of a given facility will vary greatly according to who is making the justification. One participant stated that large facilities such as the synchrotron source did not have much direct value for the aircraft

industry, for example. He claimed that it would be hard to justify current facilities on the basis of direct assistance to our national economy. He felt that those deciding about facilities should pay more attention to the "real world" and what is needed to help the economy. Another participant said, however, that such facilities do make a direct contribution. He offered as an example the development of sensors used in manufacturing processes that were developed on the basis of surface physics carried out by these large facilities. It became clear that consideration of who would use the facilities, i.e., consideration of the customer's needs, was important in making decisions about the facilities and where they fit in a materials R&D program. Important in this consideration is that there are many different kinds of customers, so that determination of who the customer is and which customers should get priority, is just as important as what his requirements are.

B. MATERIALS RESEARCH - SCIENCE AND ENGINEERING

This session was led off with a presentation of a paper by Prof. George Dieter. (see Appendix B) The major points made in the presentation were as follows.

1. Research is best when science and engineering are intimate enough so that the distinction is difficult.
2. Fundemental engineering research, as defined in the paper, is best done in the university. It is generic research and is dedicated toward developing a knowledge or technology base.

3. Data on university faculty pursuits indicate that there has been very little shift toward materials processing research from 1978 to 1984 despite an apparent large increase in interest in the subject.

In trying to answer why this is so, the paper pointed out several reasons for the apparent lack of growth in materials engineering. These included; lack of dependable funding, concern about peer review, lack of equipment, and the need for an interdisciplinary approach. In addition, materials engineering is not taking advantage of modern technological changes such as computerized design and manufacturing that are found in other engineering disciplines.

Definition of Materials Engineering: In the ensuing discussion one participant stated that the definition of materials engineering, as presented, was too narrow. There were several other fields where considerable research was going on that could qualify as materials engineering, particularly in the electronics area. Further, these fields were making use of of new, computerized design methodology and techniques. Other participants endorsed this assertion about the narrowness of the definition. One stated that much materials engineering work was being done at the interface of various engineering disciplines. Another claimed that the "sociology" of the materials field leads to most of materials engineering work being done in other engineering fields such as electronics. There was disagreement, however, about including many of the other engineering areas as materials engineering. It was claimed that the fact that those other fields -- which effectively combined different engineering disciplines -- are flourishing was a testimony to their ability to develop close coupling between science and engineering, and the acceptance of those interdisciplinary fields by the academic community.

Regardless of the definition, a point was made that close coupling between engineering and science was needed. One participant stated that the U.S. must respond to the needs for materials engineering, i.e., those that bridge the gap between engineering disciplines in order to carry materials science to products. Another asserted that materials engineering should be done in the universities if for nothing else than to educate materials engineers. He stated that now, industry must do this job.

Science and Engineering Linkage: The point was made by many of the workshop, however, that the barriers between disciplines were falling, primarily in industry, but also in the universities. One participant observed that the polymeric composite program at MIT was a good example of this breakdown. This is a broad research program cutting across many disciplines, and that the students being turned out are very much attuned to an interdisciplinary approach. He believes that such "grassroots" efforts are leading to a good balance between engineering and science, although a bit more of a "superstructure" would be helpful. Another participant stated that closer cooperation between industry and the universities could accelerate the growth of these kinds of programs. In general, many participants felt that there was a greater amount of interdisciplinary efforts going on than was apparent from the data presented in the lead-off paper, and that much progress was being made toward a closer materials science/engineering link.

A caution was raised by one participant that one should not go too far in emphasizing an interdisciplinary approach. He stated that it is important to recognize that disciplinary studies are still essential. He believes that an interdisciplinary approach is one in which people of different disciplines work together. Another participant stated that the important thing is the

capability of people of different disciplines to work together. The people trained in such an environment are important regardless of their stated discipline.

Some participants claimed that progress toward an interdisciplinary approach in the universities was slower than appeared. They stated that many, "deepseated cultural barriers" still exist within the academic materials research community toward the kind of interdisciplinary work under discussion. University participants stated it is still very hard to get an interdisciplinary materials research effort underway at a university, although progress is being made. In this connection, one pointed out that the distribution of research is important in determining the direction of University departments. For example, he stated that most mechanical engineering departments do not teach manufacturing processes because there is very little process research going on. Yet that department is where the people who work in the manufacturing industry come from. Another participant added that it has been easier to define research in terms of science than engineering although the latter is just as important. He claimed that part of the cultural problem acting against materials engineering research was that many of the materials problems "are not exciting enough" to draw significant research interest.

Many of these participants admitted, however, that shifts in research funding that emphasized engineering and interdisciplinary approaches could reduce these "cultural barriers". It was pointed out by another participant that these "cultural" problems also can be gotten around by going to "subcultures" that exist in any university environment. By emphasizing those subcultures which are willing to try new approaches and are not bound to

prevailing organizational structures, a sound materials engineering research program could be developed from within the system. In general, however, there was little concern that the balance between engineering and science was a serious problem, in that progress was being made in correcting imbalances.

Importance of Materials Engineering: In response to a request for views from workshop observers about the importance of materials engineering, representatives of several Federal agencies spoke. One offered the observation that the materials community may be building artifical barriers, and that more materials engineering is going on than was indicated. Another, with experience in different materials R&D funding agencies, stated that some agencies make a distinction between materials science and engineering while others do not. It is his belief that the agency "culture" decides this. A third said that materials science and engineering research are often the same, and the distinction depends on who is looking at the research. He cited the welding research program as an example. Finally, a fourth said that research in his organization is driven primarily by applications. In his view the distinction between materials engineering and science research is that the former is driven by building a product while the latter is driven by the desire to secure understanding. He also stated that the proper balance of science and engineering depends very much on the particular program and cannot be set in advance for all materials R&D.

A final comment was made about the importance of distinguishing between Federal policy and budget policy. This participant stated that it is proper for a National policy, to be described by the Congress, to enhance industrial development without budgetary help to promote specific industrial activities.

Directing Research: In response to a question about the capability of directing research into specfic areas, the workshop agreed that that was possible but there were several pitfalls in doing so. One participant stated that the Federal government has channeled research toward particular materials, but that they have not always chosen the "proper" goals for that research. Another asserted that a major problem arose in determining when "enough is enough". He said that diligent, detailed review of the directed research activity is necessary to know when the program has run its course. Another participant stated that it is very important to listen to who has the problem as well as who does the research. The important thing is to match the solutions to the problems. Others countered that this is not always easy to do. For generic research it is difficult to identify specific customers. However, they added, one can still address the question by reviewing the needs of classes of customers. One participant offered the examples of welding and corrosion research which were topics for which a very broad class of customers exist.

Implementing Research Results: The workshop next raised the issue of implementation of research results. One participant stated that the the materials R&D program was responsible for meeting two goals. The first was to develop the technology base; i.e., the bank of knowledge on which new products are based, and the second was to reduce the time needed for implementation of that knowledge. Two participants asserted that a Federal role in implementation was not required because industry was capable of picking up the knowledge it needed. This concern was voiced about major demonstration programs, however, and it is quite possible that a Federal role in technology transfer remains.

During this discussion, the issue of product liability was raised. Several participants pointed out that concerns over litagation were sufficient to induce considerable caution in introducing new products to the market. One participant stated that such concerns could be reduced substantially by carrying out a very rigorous development program. Product liability concerns, however, appear to be a barrier to innovation and may seriously inhibit implementation of materials R&D results.

A related issue is export control which some participants felt impedes effective technology transfer. One participant pointed out that the spectre of export control is altering the way the Japanese acquire information from the U.S. They are concerned that export control will block the flow of information across international borders, so they are setting up R&D activities in this country to assure continued access.

C. RESEARCH ESTABLISHMENTS

This session was led off by a presentation of a background paper by Dr. Thomas Moss. (see Appendix B) The major points of that presentation are as follows:

1. An important goal in materials R&D is to manage more efffectively the various parts of the research establishment. One way to do this is through the use of networks that link industry, the universities and the national labs in joint efforts.
2. While each of the players has strengths and weaknesses, the important objective is to be task oriented and to seek out those places that can get the job done. The key is to adopt a flexible approach and to be willing to experiment with different arrangements.

3. Setting up networks between organizations in order to best accomplish a given task can be very effective. Guidelines in research grants, such as those for the NSF engineering research centers and the Thomas Edison Innovation Program in Ohio, can "force" such networking.

4. It is important to set goals and priorities for materials R&D in order to determine the most effective networks.

5. There is evidence that the materials R&D program is not putting enough emphasis on defining the task and getting on with the job, and putting too much on how to "slice up the pie".

Networking Between Industry and Universities: One participant responded to the presentation with concern that the efforts on the state level may not be effective because they are focused too narrowly. In particular they are concerned more with creating jobs and less so with solving technical problems. This was countered with the statement that the network arrangement between industry and the universities would ensure that the correct problems are being attacked. The willingness of industry to put their money in is proof that the goals are proper. This demonstrates the importance of staying "close to the market". Another participant, in emphasizing the importance of the market in determining research goals, pointed out that competitive forces have shortened the time we can wait to see if materials R&D programs succeed. He stated that both industry and universities must move faster in carrying out their programs.

In agreeing with the concept of networking, one participant pointed out that one of the special aspects of materials is the use of materials science by industry. This aspect facilitates networking because a natural link already exists between universities and industry. It was also stated that it

is best that the performers be linked from below rather than trying to slice up the program from the top in an attempt to forge connections. In this way balance or the right mix can be achieved by "fine-tuning" the system that is created by the linkages formed under a task oriented approach.

Research Balance: In response to a question about how the materials R&D program can acheive the most effective balance, or right mix, in the selection of what research is needed and who best to carry out this research, many participants expressed the view that the peer review system was the best way to ensure the proper balance. One participant stated that the complex peer review system contains a "natural balancing mechanism" which responds rapidly to new ideas as they emerge. He also stated, however, that the establishment of centers or large facilities can endanger this process since you now have an institution to deal with which has its own goal of continually justifying its existance. Another participant took issue with the notion that the peer review process was the best way to ensure balance. He claimed that small businesses were effectively left out of the process. It was his assertion that contract awards are not always made on the basis of the quality of the proposal, but, at times, showed bias toward certain institutions.

Concern was expressed by one participant that attempts to ensure balance among research establishments by some external manner would preempt the "natural consensus building" that exists with the current review process. He pointed out that the Federal government essentially preempted industry as a customer for university R&D in the 1950s. That is now swinging back but he is not sure if the balance is now correct. Another stated that "desperation" for facilities can lead one to bypass the established process which can upset the a balance derived on the basis of the quality of the work. A third

participant stated the best way to determine how to sort out how and where the research is done is by staying close to the market. He said that you cannot approach that determination by asking questions such as what is the proper number of large facilities. This sentiment was echoed by a participant who reiterated the importance of "grassroots" consensus building in making determinations about choices of facilities and the distribution of research. This "grassroots" approach gives the best indication of real commitment.

Education: The mention of the market also brought the view that it is the best way to ensure that universities are educating the right kinds of students. This statement was seconded by another participant who added that he believed that networking was the best way to bring in the market, in this case industry. He pointed out that the shift toward materials engineering was a response to that market. In that connection, most participants felt that the universities are responding well to changing market conditions; i.e., the need for more engineers and changing technology needs. It was pointed out that students move quickly to the exciting areas, and that students today are more aware than ever as to what they want to do and how to get there. Another participant expressed the opinion that universities are doing a better job of educating students to be engineers than industry is of training these engineers once they begin work.

One participant entered a note of caution, however, in that he was concerned that this "response" on the part of the universities was not uniform in terms of beneficiaries. In particular, he felt that smaller companies may not have benefitted as much as the larger companies as far as improved quality of engineers coming from universities. Also, he expressed concern that the "average" student may be receiving less attention because of the large increase in engineering enrollments.

Oversight of Federal Materials R&D: A final question in this session was posed about ways to oversee or direct a Federal materials R&D effort. One participant restated the view that the peer review system was a good way to ensure that the materials R&D program has the right mix. In particular he said that examination of materials research centers and the process by which they are established would be a good indication of the balance of research in the materials area. A cautionary note was raised to the effect that determination of the proper mix of materials R&D facilities, projects and establishments would require analysis "more global than the peer-review process can assure".

Another comment to the question on program oversight was that the biggest barrier to implementing new process technologies is the lack of effective management systems; i.e., methods to translate new technologies into manufacturing systems. He suggested the establishment of a center of manufacturing systems to develop the more effective methods of using new process technology. Another participant believes the present materials R&D system is alright for small science but it favors the extension of past research over "truly new ideas". He believes that there should be support set aside for innovative ideas. A third suggested the establishment of a National Institute of Materials along the lines of the National Institute of Health. This institute could look at specific problems in materials. This idea was countered by a participant who felt that such an institute would "segment" materials R&D. He believes that the important thing is to integrate research and manufacturing, and that more vertical connection is needed.

D. CROSS-CUTTING

The final session was devoted to addressing questions that attempted to integrate the three previous sessions, and to bring forth some ideas about goal and priority setting. There were several ideas raised during this session and the following is a summary of those comments.

Materials Processing: The notion that materials processing needs to be given a higher priority in materials R&D was raised again. As to setting goals, a participant suggested that Congress should not be doing this, but should facilitate the setting of goals by the materials community. In other words he felt that Congress should take steps to make it easier for the materials community to pursue its own course. In response to a question he felt that the National Council on Critical Materials could be a way to do this as is this workshop itself. Another participant agreed in that he felt it was possible for the industry to set goals through various mechinisms similar to the Microelectronics and Computor Corporation now being set up by a portion of the electronics industry. He felt that the National Council on Critical Materials should set up goal setting mechanims rather that set goals itself.

Achievement of Goals: A point was made by another participant that the measurement of progress toward goals would require a great deal of sophistication by the Congress. He felt that it was perhaps best to leave such measurement to the materials R&D program managers. Another offered th idea that perhaps a "visiting committee" structure within the Congress similar to those in many universities could be a way to measure attainment of goals.

Goal Setting: One participant said that there are obvious technical and scientific needs, and what is needed is someone to set a "vision". Another

stated that it is easy to set technical goals but harder to set research goals. He felt that quality control of the research would perhaps be a better goal. A third participant added that it is important to assess engineering and science needs, but probably impossible to do so for the complete field of materials. He felt that the assessment should concentrate on subareas. The importance of incorporating computational techniques in design and analysis was again pointed out. This participant said that the application of these techniques is still lacking in materials R&D. He felt that the organizational structure of materials R&D needed changing to more effectively bring in this new knowledge. Finally, it was pointed out the the funding agencies pretty well know where the key technical areas are. What is more important, he stated, is to learn how to manage the R&D resources more effectively. He stated that we have the questions identified on how to do this, which is a major step, but we still need to find the right answers.

APPENDIX A

Workshop Attendees

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CONGRESSIONAL WORKSHOP ON MATERIALS R&D

JANUARY 15, 1985

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APPENDIX B

Description of Terms

INVENTORY OF FEDERAL MATERIALS RESEARCH AND TECHNOLOGY

FISCAL YEAR 1982

Executive Office of the President
Office of Science and Technology Policy

FEDERAL COORDINATING COUNCIL FOR SCIENCE, ENGINEERING AND TECHNOLOGY
COMMITTEE ON MATERIALS

JUNE 1983

III. DESCRIPTIONS OF TERMS

Materials

For purposes of the COMAT inventory, the term "materials" is considered to have a range of connotations and refers to any substance which is segregated, introduced, or used by man in performance of functions. The COMAT inventory includes all aspects of R&T commitments to all stages in the life cycle of materials, ranging from the identification of natural resources to their final stage of recycle or disposal. It is concerned with both renewable and non-renewable resources, through their transition from raw materials into industrial and consumer materials, as well as to their consumption and use. "Materials" is accordingly defined to include such substances as geologic materials, raw minerals, metals, composites, ceramics, semiconductors, dielectrics, glasses, polymers, wood, fiber, leather and other nonfood agricultural and animal products, by-products, scrap and wastes. R&T on processing coal, gas, oil, and nuclear fuel materials is included, but not on their use as fuels. In addition to the more commonly recognized materials of manufacture, "nonmanufactured" materials are included. Specifically excluded from this inventory are materials being used for food and drugs.

Minerals

As recently adopted by Interior's Bureau of Mines and Geological Survey, the term "minerals" as used in relation to resources is defined as a concentration of naturally occurring solid, liquid, or gaseous materials in or on the earth's crust in such form that economic extraction of a commodity is currently or potentially feasible. (Note: The terms "materials" and "minerals" have often been used interchangeably when referring to their application as "resources" creating a degree of confusion. For example, the earlier proposed "National Materials Policy, Research, and Organization Act of 1978" defined "materials" for legislative purposes as meaning "natural resources intended to be utilized by industry in the production of goods, with the exclusion of food and of energy fuels used as such.")

Commodities

Commodities, in the COMAT sense, are materials or minerals which are able to be used as articles of trade or commerce and from which products are manufactured.

Materials Science

Materials science is a term used to indicate the research conducted by fundamental disciplines in studying the basic nature and behavior of materials in their functional mode rather than resource mode. It encompasses both basic and applied research mainly because of the inherent problems in differentiating between the two, and has been identified in a number of ways including condensed matter and solid state sciences. It generally includes some subfields of chemistry and physics, as well as metallurgy, polymers, ceramics, and parts of various engineering disciplines. As such, it addresses a broad science base underlying microstructures, processing, properties, and performance of materials.

Materials Life Cycle

For COMAT purposes, the materials life cycle is divided into the following function stages: exploration for resources, preparation for extraction of raw materials, extraction of raw materials, processing of raw materials, manufacture and fabrication of refined materials, application and utilization of finished materials, evaluation of materials, development of new or improved materials and processes, and waste management.

National Goals

The Federal materials research and technology program is directed toward supporting the following major national goals:

Provide for the Nation's security
Provide for the Nation's economy
Provide for adequate supplies of essential materials
Provide for adequate supplies of energy
Provide for acceptable standard of living
(food, shelter, health, safety, personal security, recreation, transportation, communications, environmental quality, etc.)
Provide for national competence in science and technology

Appendix C

Background Papers

MATERIALS RESEARCH FACILITIES

BACKGROUND PAPER FOR CONGRESSIONAL WORKSHOP (1/15/85) on

ADVANCED MATERIALS R & D NATIONAL PROGRAM PLAN

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Contents:

I. Introduction

II. Large (Major) Materials Research Facilities

III. Medium-scale Materials Research Facilities

IV. Small-scale Materials Research Facilities

V. Federal Materials R & D: Comments and Issues

Appendix 1. MMF Report: Materials Research Facilities and Modes and Specialized Facilities

I. Introduction

Materials research (science and technology) deals with the diverse properties of solids and liquids and their interfaces. It is interdisciplinary, involving materials science, including metallurgy, ceramics, polymers, major subareas of physics and chemistry, and special subareas of many areas, i.e. earth sciences, biology, medicine, etc. Like all science and technology activities, progress in materials R & D depends on people, organizations, and facilities and instrumentation. These facilities and instruments range from laboratory size instruments to medium scale instruments (~$100K to $1M) to major national facilities such as sources of synchrotron radiation and neutrons. They all play a vital role in our national materials R & D program, which involves the universities, industry, and federal and non-profit institutions.

In the following, materials research facilities will be discussed within three categories:

- Large (major) facilities
- Medium-scale facilities
- Small-scale facilities

These categories will be taken as described in a recent NRC report entitled Major Facilities for Materials Research and Related Disciplines (MMF). In this report, three types of materials research facilities were considered as major facilities, i.e., facilities involving synchrotron radiation, neutrons, and high magnetic fields, while other materials facilities were considered as medium-scale. The following descriptions of major (large) and medium-scale materials R & D facilities consist mainly of excerpts from this recent MMF report, which addressed only these major facility capabilities needed to support future U.S. activities in materials research.

II. Major Materials Facilities (from MMF Report Executive Summary)

The relatively high costs of major facilities for materials research dictate that priorities be established; and a recent NRC Committee (MMF) has recommended priorities for major new facilities and new capabilities at existing facilities, for materials research and related fields over the next decade and beyond. The recommended priorities involve three types of facilities, providing synchrotron radiation, neutrons, and high magnetic fields.

Synchrotron radiation, produced when energetic electrons are deflected by a magnetic field, provides over a broad spectral range the most intense source of photons now available. Such radiation can be intensified further by orders of magnitude by using insertion devices--wigglers and undulators--that put a series of sharp bends in the electron trajectories. Synchrotron-produced photons interact strongly with atomic electrons, thus offering a means of probing the details of the electronic structure of materials as well as a means of probing the atomic structure of materials.

In contrast, neutrons, which are produced by nuclear reactions, interact most strongly with atomic nucleii. Neutrons are thus uniquely suited to the study of lattice dynamics and molecular configurations. In addition, since the neutron has a magnetic moment, neutron scattering offers a unqiue means of probing the magentic properties of materials. The most effective use cold neutrons, which have very low velocities, requires that they be transported through special tubes, whose walls reflect those neutrons with minimum loss, to large experimental areas called guide halls.

High magnetic fields are essential to the study of a variety of technical and fundamental problems. In particular, high magnetic field facilities are essential to the development of improved superconductors and, in turn, make it possible to construct more efficient superconducting magnets capable of achieving still higher fields.

The Committee applied the following criteria in establishing its priorities:

- The importance of each facility for frontier research in materials, and consideration of research needs of other fields, including biology, chemistry, atomic and molecular physics, plasma physics, earth science, and medical science.
- The importance of each facility for applied research in areas of national priority; that is, economic competitiveness and security.
- The availability of other, less costly alternatives for accomplishing comparable scientific, technological, and educational goals.
- The contribution of each facility to a long-term national plan for such facilities, including considerations such as capital investment, operations costs, and technical feasibility.

Additional criteria that should be considered in evaluating proposals for new facilities include:

- Technical and scientific resources at the laboratory or university site, including schools or departments in related areas.
- Access and ease of use by extramural academic, industrial, or government laboratory investigators.
- Role of the facility relative to a new or strengthened mission of its home laboratory or university.
- Potential of each facility for training scientists and engineers.

Further, new facilities to be fully effective must be dedicated, that is, used exclusively for synchrotron radiation or neutron based

research. Finally, to serve the entire community optimally, the geographic distribution of facilities should generally be taken into account.

CONCLUSIONS AND RECOMMENDATIONS

The Committee's recommended priorities for major facilities--both new facilities and new capabilities at existing ones--embody two prerequisites:

- That they are accompanied by expanded support of smaller materials research programs, including related instrumentation. Research on this scale continues to provide much of the fundamental new science in the field and to train a large fraction of our scientific and technical manpower.

- That resources must be provided to operate existing user facilities productively. In addition, the approved enhancements of major synchrotron radiation facilities at the Brookhaven National Laboratory, Stanford University, and the University of Wisconsin should be completed expeditiously, since it will require several years to more than a decade before the new facilities recommended in this report can contribute to the research effort of the United States.

RECOMMENDED PRIORITIES

The Committee's recommended priorities for the development and construction of facilities during the next decade include two categories:

- Major new facilities, and

- New capabilities at existing facilities.

These categories complement one another in function, time scale, and required resources. New capabilities at existing facilities are essential for scientific and technological needs in the next decade, while the long lead times needed to construct major new synchrotron radiation and neutron facilities require that we start now with the planning and design of such new facilities. They also require that we begin immediately to implement new capabilities at existing facilities. The Committee concludes that both categories are essential for the effective evolution of science and advanced technology in the United States in the next decade and beyond.

The Committee also recommends the convening of additional panels to address other important aspects of materials research.

Table III.1 REQUIREMENTS FOR NEW FUNDING*

MAJOR NEW FACILITIES (Millions of FY 85 Dollars)

In order of priority:

1.	6 GeV SR Facility	$ 160
2.	Steady State Neutron Source Facility	260
3.	1 to 2 GeV SR Facility	70
4.	High Intensity Pulsed Neutron Source Facility	330

NEW CAPABILITIES AT EXISTING FACILITIES (Millions of FY 85 Dollars)

In order of priority:

1.	Centers for Cold Neutron Research	$ 25-35 each
2.	Insertion Devices on Existing SR Facilities	20
3.	Experimental Hall and Instrumentation at LANL	15
4.	National Magnet Laboratory Upgrade	5
5.	Enriched Pulsed Neutron Target	2-5

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* The Committee's estimates for construction and initial instrumentation costs are largely based on information from facility presentations, program officers, and other knowledgeable colleagues.

An important issue is that interest in materials research is derived from both fundamental science and technology. Materials research is an intellectually stimulating area of science, as shown by the discoveries of fundamentally new phenomena, concepts, and states of matter, and as manifested by several Nobel Prizes. Materials research supports advanced technology, which together with engineering is the foundation for our technology applications (manufacturing) in areas of national priority, including those of information systems, energy, transportation, national security, and health. Large (major), medium- and small-scale facilities and instrumentation are all required to meet U.S. needs. Table II.1 summarizes the connection between subareas of materials research using major facilities and technological applications. Major materials facilities offer a breadth of techniques, indeed they can be viewed as a large collection of small facilties; to indicate this breadth, a partial list of available techniques is summarized in Table II.2.

Table II.1. Connection Between Materials Research Subareas and Other Fields that Utilize Major Materials Facilities and Technological Applications of National Interest

	Information Systems (computers, communications, electronics)	Energy (fossil, nuclear, fusion, solar,...)	Health (Medical, Biotechnology, Environmental)	National Security	Transportation (ground, air, space)
Semiconductors	+	+	+	+	+
Metals and alloys	+	+	+	+	+
Insulators	+	+		+	+
Polymers	+	+	+	+	+
Ceramics	+	+		+	+
Magnetic Materials	+	+	+	+	+
Catalysts		+	+	+	+
Adsorbates		+	+	+	+
Lamellar (layered) materials	+	+		+	+
Composites		+	+	+	+
Biological molecules, macromolecules, and membranes			+		
Gaseous molecules and atoms	+	+	+	+	+
Plasmas (atoms, ions)		+	+	+	

* In addition to bulk materials, thin films, interfaces, and surfaces of several of the above materials are of major scientific and technological importance.

TABLE II.2. Techniques Available at Synchrotron Radiation and Neutron Facilities

		Photons	
	Neutrons	X-ray	Soft X-ray and VUV
I. Elastic scattering*			
Bulk crystallography	x	x	
Surface crystallography	x	x	
Molecular cystallography	x	x	
Small angle scattering	x	x	
Polarized scattering	x		
Magnetic scattering	x		
Diffuse scattering	x	x	
II. Quasielastic scattering			
Diffusion	x		
Reorientation	x		
Critical dynamics	x		
III. Spectroscopy and elemental analysis			
Inelastic (E,k) scattering			
- electrons		x	x
- phonons	x		
- magnons	x		
Absorption, reflection, fluorescence		x	x
Absorption spectroscopy			
- EXAFS		x	x
- SEXAFS		x	x
- PHD		x	x
Photoelectron spectroscopy			
- core level		x	x
- valence level		x	x
- ARPES		x	x
- yield spectroscopy		x	x
Photon stimulated desorption			x
Photo chemistry		x	x
Activation analysis	x		
IV. Imaging and microscopy			
Microscopy			x
Microprobe		x	x
Depth profiling	x	x	
Topography	x	x	
Lithography			x
Interferometry	x	x	
Radiography	x	x	
Autoradiography	x		
Holography			x
V. Radiation effects			
Radiation damage	x	x	x
Isotope production	x		
Transmutation doping	x		

III. Medium-scale Materials Research Facilities

Medium-scale materials research facilities can be categorized as interdisciplinary research organizations, such as the Materials Research Laboratories (with goals having some focus) as well as special-purpose laboratories or centers for materials research such as those on polymers, ceramics, and materials processing and other focused subareas of materials research. A partial list of such facilities or centers is as follows:

- Polymers, ceramics, metals & alloys
- Materials processing
- Microelectronics process facilities
- Electron microscopes
- Lasers: FEL, processing, VUV
- Ion beam facilities
- Computation facilities
- High and ultra-low temperature

These "focused" facilities or centers typically involve combinations of materials synthesis, processing, and characterization, with an organizational structure and instrumentation (typically several medium-scale instruments ($100K-$1M).

Such medium-scale interdisciplinary or focused materials laboratories and centers represent a very important part of our overall national materials research program and they fulfill national needs not otherwise satisfied by academic, governmental, or industrial laboratories. Indeed, all three performer sectors - university, industry, and federal and non-profit laboratories - actively support such medium-scale facilities, which can easily cost more than $5 to $10 million. These medium-scale facilities or laboratories differ from the major facilities described previously in that they involve people, organization and an "open-ended" collection of small and medium instrumentation ($100K-$1M) whose magnitude and nature depend explicitly on specific goals. In contrast with MMF facilities, capital investments required by such medium-scale facilities can be afforded by all three performer sectors, i.e. a very large central start-up capital investment such as required for a synchrotron radiation or neutron facility is not required.

The MMF Committee of the NRC heard excellent arguments for new facilities or this type, each of which can easily cost more than $5 to 10 million. However, the Committee excluded consideration of them without prejudice. It did so in part because of their "open-ended" nature. They require fuller definition through the formulation of specific proposals by specific institutions. The Committee did not request development of the details of such proposals when they were not already well formulated. Further considerations of important medium-scale materials research laboratories and centers were deferred for future planning committees. Medium-scale facilities can (and in many cases do) play an important role in all the materials research subareas in Table II.1 as well as other subareas.

Clearly, the absolute level and balance between investments in large (major) facilities and medium-scale facilities and instrumentation, both of which are essential, remain an important (and complex) issue.

IV. Small-scale Materials Research Facilities

In this category, I include materials research groups (NSF term) and small groups of collaborating individual researchers. For this category, people are of central importance. An important issue again is that of instrumentation, both small and medium ($100K-$1M) scale, which is essential to forefront research. Often, a materials research group (MRG) is focused around one or two medium-scale instruments (NMR, MBE, electron microscope, etc.) As with large and medium-scale facilities, this mode of materials research is essential for all the subareas in Table II.1 (plus other subareas). Moreover, this research mode in the universities is responsible for training many of our scientists and engineers.

V. Federal Materials R & D Program: Comments and Issues

The following comments and issues are offered for the purpose of helping provide a clearer definition of some of the issues to be addressed relative to the implementation of the Critical Materials Act of 1984. Such an implementation involves the establishment of a policy and review processes, and for coordinating and implementing that policy. These comments and issues are in general applicable to both our federal materials R & D program as well as to the facilities and instrumentation elements contained therein.

- General policy (strategies/goals) for the various performers - Federal, university, industry - need to be established in response to identified national priorities.

- According to the strategy (policy) and programs of the performers in the various subareas of materials R & D, each will require a certain style or mode of research and certain type(s) of facility(s) and other instrumentation.

- A diverse spectrum of materials R & D styles, people skills, organizations (modes), facilities and instrumentation is required to support the U.S. needs.

- The level and balance of small, medium, and large materials facilities should be determined by the use of criteria (parameters) for establishing priorities within and between the various subareas of our national R & D program and within and between the various subareas of materials R & D. An emphasis should be placed on the goals (i.e., "product" and "customer") of the various performers in these subareas.

Issues & Factors: Federal Materials R & D Program

I. Policy

- The strategic importance of materials R & D to our national priorities (science, economic, security)
- Long Term Strategy (flexible, general) supporting national priorities

II. Reviews

- Environment: understand the past and present status of Materials R & D and the balance between many subareas
- Understand the connections between the federal program and national application needs (i.e., federal, university, industry)
- Assess the long term needs of materials research R & D (many subareas)

III. Federal Coordination and Program Implementation

- Yearly (policy, economic factors)
- International competition (multinational corps.)
- Technical Personnel (science and engineering)
- Facilities (all) and instrumentation: objective, multiple review processes (technical excellence, open competition; balance)
- Efficient information/"technology" transfer ("customer" involvement)

APPENDIX 1

MMF REPORT

MATERIALS RESEARCH FACILITIES AND MODES AND SPECIALIZED FACILITIES

Materials research is by its nature interdisciplinary, historically calling on expertise from engineering, physics, earth sciences, and chemistry and, recently, extending to biology and medicine.

In this chapter, we briefly describe the diverse research styles and types of facilities, instrumentation requirements, organizations, and modes of materials research. This is intended to set the context for the focus of the report: major neutron, synchrotron radiation, and high magnetic field facilities, costing in excess of about $5 million. These are all are national user facilities, each serving a group or groups of users whose interests often extend beyond the traditional materials research community. This focus responds to the charge to the committee, as stated in the opening sentences of the Preface and the Executive Summary.

Universities, the federal government, and private corporations are all involved in materials research. In universities, it is done in the main in different disciplinary departments. Within the government, it is done within facilities operated for the U.S. Department of Energy by private contractors, such as the Oak Ridge National Laboratory, the in-house laboratories of the Department of Defense, such as the Naval Research Laboratory, and other laboratories such as the National Bureau of Standards. Numerous industrial laboratories are also involved in materials research, usually in an interdisciplinary mode, ranging in focus from fundamental work to development and manufacturing.

UNIVERSITIES

Much of the materials research in the United States is done in small university laboratories, consisting of a few researchers and a total instrumentation inventory of less than $1 million. Research on this scale continues to provide important, fundamental new science and to train a large fraction of our scientific and technical manpower.

Universities have a crucial role in materials research. They are a major source of new ideas and concepts that often take years to mature, time that industry often cannot commit. And they are the sole source of future materials scientists and engineers. Universities also

operate special research facilities that are used by a broader research community.

Training new scientists and engineers for materials research is complicated by the needs of advanced technology for people who are broadly trained and fully conversant across the conventional disciplinary boundaries, such as, for example, condensed-matter physics and chemical engineering.

An important task for the universities is to develop stronger ties with industrial and governmental laboratories. Such cooperative programs stimulate new research, promote the exchange of new knowledge and technology, and help in thecontinuing education of mature technical personnel at industrial and governmental laboratories.

Materials Research Laboratories

The Materials Research Laboratory (MRL) program, supported by the National Science Foundation and the Department of Energy, is intended to stimulate interdisciplinary materials research within universities, of the sort not easily done under the traditional funding pattern of individual research projects. It emphasizes coherent, multi-investigator projects requiring collaboration among individuals in two or more materials-related disciplines. The MRL program has also emphasized the development of wellstaffed and well-equipped central research facilities, partly as mechanisms for stimulating collaboration. Finally, new projects can be quickly started with MRL funding including seed funds to assist both new faculty members and established faculty members with novel ideas or programs who wish to change research fields. MRL core support is not intended as a substitute for individual research project funding, but may properly catalyze significant new research initiatives. Several Materials Research Centers at universities are funded by the Department of Energy and by other agencies. A smaller kind of specialized program, the Materials Research Group, is currently under consideration by NSF.

Instrumentation for Materials Research*

The status of instrumentation in university research laboratories was examined in a 1971 study of the National Research Council (reference 23), commissioned by the National Science Foundation. At that time, a need for $200 million in new instrumentation was identified. Only a small fraction of the need was met at the time, leading to a more problematical situation now. Thus, in the intervening decade, the consumer

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* While this discussion of instrumentation focuses on the needs of the universities, many of the same problems are faced by governmental laboratories engaged in materials research.

price index rose by slightly more than a factor of three, while instrumentation costs inflated at almost twice that rate. The accumulated need is now at least $1 billion, and some estimates are considerably higher. The $1 billion estimate is what would be needed to bring university research laboratories up to modern standards and does not include the cost of major new facilities, such as reactors or accelerators. Results from a 1984 National Science Foundation instrumentation survey (reference 24) indicate that only 16 percent of current academic research equipment in the physical sciences could be characterized as "state of the art." Dealing with this crisis in university instrumentation is a matter of national urgency.

Small- and Large-Scale Instrumentation. Exacerbating the shortcomings in university instrumentation is the increasing need for new larger-scale instrumentation for small research groups, instrumentation that is expensive by traditional standards but modest by those of the national facilities. In some cases, the cost of such instrumentation, typically $250,000 to $1,000,000, will necessitate considerable sharing, usually with other investigators or groups at the same institution. Examples include electron microscopes, the new generations of high-powered or very fast lasers, equipment for studying specialized materials, such as molecular beam epitaxy or chemical vapor deposition apparatus, specialized environments such as "clean rooms," very high powered or pulsed magnets, and dedicated 32-bit superminicomputers.

The cost of equipping many experimental stations at large user laboratories is also in this category. For example, most of the beam lines at existing synchrotron radiation facilities now are financed by participating research teams from governmental, industry, and university laboratories. These groups provide their own funding for instrumenting ports to do particular kinds of experiments. It is expected that about half of the additional beam lines proposed in this report for the new and enhanced synchrotron radiation facilities will be funded by the research participants. Future neutron facilities may also be partly developed in this mode.

Large-Scale Computers. Over the past decade, a new and essentially different kind of instrument has been added to the increasingly complex instruments for experimental materials science: the large-scale computer, or supercomputer. Although simple properties of simple systems, such as the cohesive energies of elemental solids, can be calculated within about 10 hours with a 32-bit superminicomputer, calculations for more complex and interesting systems require vastly larger memory and increased computing speed. Greatly increased computing support, during the next 5 to 10 years, would qualitatively affect the usefulness of theory for the solution of materials problems.

Personnel

The need to fully use the facilities discussed here, coupled with the generally complex nature of modern materials research, implies a much more extensive use of technical and professional support staff in individual research groups than has been customary in the chemistry, physics, and materials science communities in universities. Biological scientists in universities are now well established in this mode of operation, as are many physical scientists in industrial and governmental laboratories.

FEDERAL LABORATORIES

The federally supported laboratories have widely diverse roles in U.S. materials science and technology, in keeping with the missions of their agencies. Thus, the national laboratories of the U.S. Department of Energy (DOE) conduct materials research related to the development of nuclear fission, fusion, and other energy sources, as well as to weapons. As do other federally supported laboratories, the DOE laboratories also operate special research facilities that are widely used by the broader scientific community. In fact, the special scientific or measurement capabilities, as well as the major facilities, of the federal laboratories, are the basis for their many cooperative research efforts with industry and universities.

The materials research and development activities of the laboratories of the Department of Defense (DOD) directly support general defense needs or particular weapon systems. Fundamental work in materials research centers on those activities areas inadequately addressed by the private sector or activities that may have an important long-range impact on the scientific or technological needs of future defense capabilities. Overall, the DOD laboratories can engage, when it is necessary, in all aspects of materials research and development, from fundamental concepts to providing prototypes. Finally, the direct role of the DOD in materials research is complemented by its indirect role in broadly supporting contract R&D at academic, industrial, and governmental laboratories of other agencies.

Other governmental departments and agencies also have major roles in materials research. For example, one of the central missions of the National Bureau of Standards, within the Department of Commerce, is research leading to new or improved measurement methods and standards and to basic understanding of the properties of materials needed by industry, universities, and government. The U.S. Geological Survey, within the Department of the Interior, has a major effort in basic and applied materials research related to the nation's mineral resources.

INDUSTRY

Condensed matter science is unusual in that a significant portion of basic research in the U.S. is performed in industry. This reflects the

fact that condensed matter science supports advanced technologies in many areas of national priority, including those of information systems, energy, health, transportation, and national security. Basic industrial research is conducted in all sub-areas of condensed matter science using many modes, ranging from the individual researcher to research groups. Industrial researchers also make active use of national facilities and collaborate in these efforts with university and governmental researchers. Multidisciplinary materials research is often carried out effectively at the major U.S. industrial research laboratories.

In addition to playing a major role in basic materials research, industry also helps define the future materials needed to advance important key technologies. That, in turn, serves as a guide to research at university and governmental laboratories as well as at industry laboratories.

The largest materials research effort in the U.S. undoubtedly is the industrial research and development effort focused upon product lines. Because this effort often requires advanced applications of materials for specialized uses, it generally requires a fundamental understanding of materials. The availability of university-trained scientific and technical personnel is essential for this extensive industrial research and development. Collaboration by industry researchers, with scientists and engineers at both university and governmental laboratories, contributes substantially to technology transfer. Recently, specialized facilities, such as microelectronics-related facilities, have been created at universities to address both basic research and the technology needs in industry.

OTHER SPECIALIZED FACILITIES CONSIDERED BY THE COMMITTEE

In addition to facilities for synchrotron radiation, neutron scattering, and high magnetic fields, the Committee surveyed other major facility needs and opportunities during the course of its study. However, none was identified that qualified for the priorities under the guidelines, namely $5 million minimum cost, established by the Committee's charter. We summarize here the specific items considered and the reasons for excluding them from detailed considerations.

Medium-Scale Specialized Facilities

The Committee briefly considered interdisciplinary materials research organizations, such as the Materials Research Laboratories (MRL) funded by the NSF and DOE, as well as special-purpose materials research laboratories or such centers for materials research as those on polymers, ceramics, and materials processing and other focused sub-areas of materials research. The Committee believes that such laboratories and centers represent a very important part of our overall national materials research program and that they fulfill national needs not otherwise satisfied by academic, governmental, or industrial laboratories.

The Committee heard excellent arguments for new facilities of this type, each of which can easily cost more than $5 to 10 million. However, the Committee excluded consideration of them without prejudice. It did so in part because of their "open-ended" nature. They require fuller definition through the formulation of specific proposals by specific institutions. The Committee did not request development of the details of such proposals when they were not already well formulated. Further considerations of important materials research laboratories and centers are deferred for future planning committees.

The Committee also discussed facilities for developing microelectronics processes. These are rapidly gaining national importance as microelectronic technology reaches submicron levels in silicon, and as materials other than silicon, such as gallium arsenide, are explored. Most large-scale facilities for microelectronics processing have, quite appropriately, been established by industry, though there is also a role for universities in this area.

Also discussed were facilities for high and ultra-low temperatures as well as those involving charged-particles such as electron microscopes and ion beam facilities, which can make major contributions to the analysis, synthesis, and modification of materials. The individual costs of these generally fall below the $5M threshold used by the Committee. As a result, and without passing <u>any</u> judgment on relative merits, such facilities would be better considered as part of the analysis of serious instrumentation needs mentioned earlier in this report. Such instrumentation will play important roles in conjunction with the use of synchrotron radiation sources, in which case their costs will be included along with those of beam lines.

MATERIALS ENGINEERING vs MATERIALS SCIENCE

The billing of the program leads me to suspect that the organizers of this meeting were trying to create a confrontation between the metal beaters and the atom chasers. However, the field that we are discussing today is properly titled Materials Science and Engineering not vs Engineering. MSE is concerned with promoting the application of basic science to the development, processing and use of materials.

SLIDE 1

MSE is concerned with a two way flow of information between the basic scientists at one extreme and the user/consumer of materials at the other. The MSE process is most productive when basic understanding of a materials problem and the empirical need to solve it are mixed so intimately that it becomes difficult to tell which end of the spectrum provided the initial impetus toward a solution. However, on balance, the initial impetus comes more often from technology pull than from scientific push.

To focus on some well recognized distinctions between science and engineering for a moment. SLIDE 2 Anna Harrison, past president of AAAS gave what I think is the best brief definition of the two.

Then, when we turn to the question of what constitutes engineering research, I think Carl Hale of the NSF described it as well as anyone. SLIDE 3

Fundamental Engineering Research -- avoids use of terms basic and applied -- recognizes that in view of the difference between science and engineering that is is natural to have a continuum between basic and applied.

Research Utilization really means Development.

Fundamental Engineering Research in all its forms is appropriate to be done in universities.

Research Utilization -- generally isn't appropriate for universities

Fundamental engineering research differs chiefly from research utilization in that is is more generic, more concerned with creating a knowledge base than solving a specific problem. Some people are beginning to call this Middle Ground Research. It doesn't necessarily differ from development in subject matter but it does in breadth and intellectual content.

Let's turn now to see how a segment of the materials community involves itself in research.

Population -- metallurgy/materials science faculty in US universities -- includes those ceramists in a materials department and a few polymers people.

One activity that is clearly in the Materials Engineering camp is materials processing, design, systems analysis.

SLIDE 4 Shows how few faculty in U.S. materials science and engineering departments consider their main research interest to be in areas that are clearly enigneering oriented. There

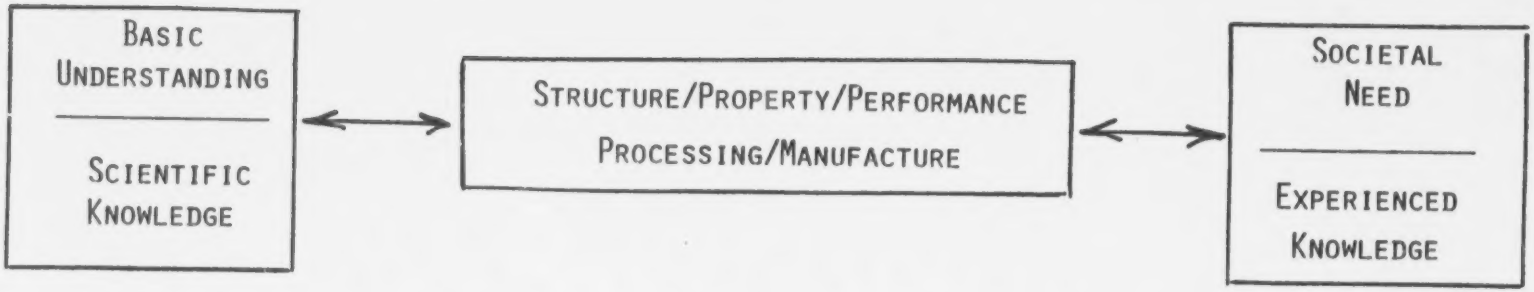
certainly are some materials engineers in the first group, labelled materials science, but not a great many.

These data show two things:

1. Preponderance of academic researchers in the one group that could be expected to be materials engineers are in fact working in materials science.
2. In spite of a 11% growth of met/mat sci fac. over 6 years there is essentially no increase in the % of faculty engaged in materials processing research. The increase is accounted for by the addition of ceramic processing and polymer processing and a more liberal counting of people in the category of design/systems which should be called other.

Thus, there is essentially no growth in faculty working in materials processing inspite of it being ballyhooed as one of the major areas for emphasis. The situation in Canada is somewhat different. SLIDE 5 A substantial percentage of Canadian faculty work in areas of research of direct concern to Canadian industry that would clearly be defined as materials engineering. SLIDE 6 shows my thoughts as to the reason this situation exists in the universities in the U.S.

It is a shame that the academic materials community is not more involved in the area of materials processing, which is highly relevant to the nation's economic well-being and to the existing developments for materials engineering which are being made possible by interactive computer graphics, computer-aided design, and the application of expert systems to design.


BASIC
UNDERSTANDING
SCIENTIFIC
KNOWLEDGE
STRUCTURE/PROPERTY/PERFORMANCE
PROCESSING/MANUFACTURE
SOCIETAL
NEED
EXPERIENCED
KNOWLEDGE

DEFINITIONS AND VIEWS ABOUT
SCIENCE vs ENGINEERING

SCIENCE IS THE PROCESS OF INVESTIGATION OF PHYSICAL AND OTHER PHENOMENA

ENGINEERING IS THE PROCESS OF INVESTIGATION OF HOW TO SOLVE PROBLEMS

TECHNOLOGY IS THE PROCESS OF PRODUCTION AND DELIVERY OF GOODS AND SERVICES

ANNA HARRISON, SCIENCE,
10 FEB., 1984

SCIENCE OUTPUT IS KNOWLEDGE AND UNDERSTANDING

BROAD AND FREE DISSEMINATION OF RESULTS

ENGINEERING OUTPUT IS THINGS AND SERVICES

KNOWLEDGE IS INCIDENTAL TO PROBLEM SOLVING

COST, PRODUCIBILITY, QUALITY ARE KEY ISSUES

SCIENCE IS CONCERNED WITH BASIC DISCOVERY

ENGINEERING IS CONCERNED WITH SYNTHESIZING KNOWLEDGE INTO PRODUCTS AND SYSTEMS.

JORDAN BARUCH, SCIENCE,
6 APRIL, 1984

FUNDAMENTAL ENGINEERING RESEARCH

FORMULATING SCIENTIFICALLY-BASED PRINCIPLES AND CONCEPTS

DEVELOPING THE KNOWLEDGE BASE THAT LEADS TO TECHNOLOGICAL DEVELOPMENT

ADVANCING THE BASIC KNOWLEDGE THAT MIGHT BE APPLIED TO ANALYSIS, SYNTHESIS AND DESIGN OF A VARIETY OF MAN-MADE SYSTEMS

RESEARCH UTILIZATION

HEAVILY PROBLEM ORIENTED

INVOLVES A SINGLE DEVICE OR SYSTEM

MULTIDISCIPLINARY ACTIVITIES

INVOLVES TECHNOLOGY TRANSFER TO INDUSTRY

FIELD OF INTEREST OF U.S. MATERIALS SCIENCE AND METALLURGY FACULTY

	1978		1984	
	No.	%	No.	%
MATERIALS SCIENCE PHYSICAL/MECHANICAL MET	656	84	710	82
EXTRACTIVE/CHEMICAL MET	39	5	42	5
MINERAL PROCESSING	17	2	22	2
MATERIALS PROCESSING	68	9	92	11
	780		866	
CASTING/SOLIDIFICATION	22		16	
DEFORMATION PROCESSING	15		18	
DESIGN/SYSTEMS	4		10	
POWDER METALLURGY	13		14	
WELDING	14		16	
CERAMIC PROCESSING			10	
POLYMER PROCESSING			8	

SOURCE: METALLURGY/MATERIALS EDUCATION YEARBOOK
AMERICAN SOCIETY FOR METALS

FIELD OF INTEREST OF CANADIAN MATERIALS SCIENCE AND METALLURGY FACULTY

	1978		1984	
	No.	%	No.	%
Materials Science Physical/Mechanical Met	55	57	65	56
Extractive/Chemical Met	22	23	28	24
Mineral Processing	7	7	8	7
Materials Processing	12	13	15	13
	96		116	

Source: Metallurgy/Materials Education Yearbook, American Society for Metals

WHY MATERIALS ENGINEERING HAS NOT FLOURISHED IN AMERICAN UNIVERSITIES

Lack of Dependable Funding

Concern About Peer Evaluation

Lack of Equipment

Often Requires Multidisciplinary Approach

Often Requires Close Industrial Coupling

Networking the Nation's Materials Research Facilities

Statement for the Congressional Workshop on the Advanced Materials R&D National Program Plan, 1/15/85

Thomas H. Moss
Dean of Graduate Studies and Research
Case Western Reserve University

I'm sure that all who have watched the debate on national strategies for materials research and technology have noted quickly that the issues are familiar and generic, rarely unique to the focus on materials. Four key questions emerge in the concerns of the workshop:

1) the relatives emphasis on "big" vs. "small" science,
2) the best balance of "basic science" as opposed to "engineering",
3) the degree of focus on universities, national laboratories, non-profit laboratories, or industrial researchers as performers of the needed programs, and
4) the degree of reliance on planned and focused strategies vs. opportunistic response to initiative and discovery.

Scanning the news or editorials in science and engineering journals shows immediately that these issues have been consistently arising in every technical field of concern to public policy. (Appendix 1) There has been continuing controversy in my own field of physics particularly centered around the reliance on, and location of, big particle accelerators. However, few fields are unscarred by these kinds of debates.

In fact, the same questions arise within a single research university campus such as ours. We argue over investing resources in big research facilities as opposed to "starter" grants for junior faculty. We have tensions between tendencies to create focused "institutes" or "centers" as opposed to relying on individual research projects and initiatives. We worry about the balance of basic science and engineering in our budgets, curriculum, and research thrusts. And we constantly move to bring ourselves into some long-range strategic planning concept at the same time that we are confronted (or blessed) with unexpected opportunities (or disasters) which bend our path in ways we never foresaw.

The reason I mention our own scale of dealing with these issues is just to stress that we have not "solved" them and I doubt that many campuses have. The best I can say is that we wrestle with them. With that background it is clear that I cannot come to this Workshop to preach. I also can't realistically expect that the Materials R&D Program will definitively resolve these issues, and can only expect that those responsible for the Program will just "wrestle" as we have done. (Appendix 2) The key point will be to wrestle intelligently, instead of thrashing around. The issue will be to struggle with these issues in a way that learning takes place about what works in particular circumstances. We need to conduct ourselves so that strength is gained, not dissipated, with the passage of time and gathering of experience.

My assigned question for today concerns the optimal emphasis on, or use of, the major types of research establishment we have in this country: universities, national laboratories, non-profit labs., and industrial research facilities. The gist of my thinking and advice is summarized by four key points. They are all based on a fundamental assumption: since we can't really know in theory or in advance what organizational form will work best (no one has yet) we have to pursue an experimental approach, results oriented, with constant evaluation of what is working best in which area. In summary:

- pursue a diversified portfolio of research in various settings
- be constantly aware that the approach is experimental not definitive
- evaluate results and provide for change
- keep close attention to the "market" for program results, however defined (industrial use, world scientific recognition, etc.)

Above all we must avoid wasting time and energy fighting over the theoretical size and influence of the key components of the program, as opposed to using that time and energy to build mutually reinforcing networks among them. Going back to our local campus scale again I have to admit that we, like most universities, are very skilled at fighting over the division of hypothetical pies. But though this is often labeled as skilled and sophisticated politics, it

doesn't take much review of history to see that it just doesn't work. The energy is used up and lost, and no pie ever emerges to divide. My sense of this program is that in the long run the "networkers" can all win, while the clever individual maneuverers, later if not sooner, will all surely lose.

A note about the background of my thinking: I come from a somewhat unusual university. It is a relatively small, private, and yet comprehensive institution, with a diverse undergraduate college, a graduate school, and several strong professional schools: engineering, law, medicine, management, nursing, dentistry, and applied social sciences. It is a research institution, in the top 50 of all recipients of total federal research funding, despite our small numerical size. Our engineering school, for instance, has been seventh ranked of all U.S. engineering schools in terms of research support per faculty member. We are the site of one of the National Science Foundations Materials Research Laboratories, which is a source of pride and strength for us. Ours has a particularly strong engineering emphasis, one of the most oriented in that direction. My own views certainly encompass the biases of my position and institution, but I have also taken this opportunity to confer with colleagues on and off this campus on their own perception of the prospects for the Materials R&D Program. My thoughts also derive, of course, from my earlier years with a joint appointment as researcher at the IBM Research Center and physics faculty member at Columbia University, followed by a period of deep involvement

in science policy and organization issues here in Washington, as an American Physical Society Congressional Fellow, as Staff Director and Science Advisor for Congressman George Brown's personal office, and as Staff Director of the Science, Research and Technology Subcommittee of our House Science and Technology Committee hosts. I've been fortunate to be able to view a great many interesting ideas, concepts, experiments and controversies about the organization of research and technology programs.

Now, to focus on the central question: the appropriate emphasis on universities, national laboratories, industrial or not-for-profit research facilities as performers in a national materials research and technology effort. I have mentioned the central summary concepts: maintaining diversity, and building networks among the diverse establishments. The corollary is to avoid a suicidal pattern of non-productive effort or squabbling among the performers. I'm stressing a mind-set focused not on a "pie to divide", but on projects to do. Its based on a strong sense that each performer has distinct potential, with unique strengths as well as natural weaknesses. The program as a whole will best perform by drawing on synergies among the strengths and compensating for the weaknesses.

What are the general strengths and weaknesses brought by each? In outline form:

	Strengths	Weaknesses
UNIVERSITIES	Dollars invested in research projects also leverage the products of years of faculty experience, philanthropic support, student imagination and enthusiasm. They also create learning experiences and trained professionals in addition to the research output. Universities can bring together diverse skills in an atmosphere of independence and creativity that breeds imaginative new ideas. Universities have a general bias to act in the public vs. private behalf: free flow of information, insure active developemnt of ideas, etc.	Incoherence of purpose often occurs, and management is not highly directive. Academic goals and concerns can weaken attention to product or applica tion needs. Schedule and performance goals may be difficult to pin down. Experience is lacking in managing large, complex and interlocking project tasks. Process, not action oriented, in many cases.
NATIONAL LABORATORIES	The Laboratories bring experience and skill in building and maintaining big facilities. There is extensive experience in administering facilities for diverse users. Experience and skill exists in goal oriented project management. The laboratories provide reasonable, though variable, creative climate.	Complications in access to large remote facilities slows research momentum, and limits numbers of researchers involved. Necessary management structures for large facil ities introduce bureaucratic barriers and sometimes increased costs. Recent history of volatile National laboratory funding and planning, and involvement in national budget politics, has weakened attention to primary long-term research goals. There may be a focus of attention on large facilities despite opportunities in other areas. Process, not action oriented, in many cases.
INDUSTRIAL (and sometimes private, not-for-profit)	Industry and not-for-profit service laboratories bring experience in results-oriented market-tuned project management. They have experience in converting basic ideas to concrete questions of costs, practicality, marketability. Action, not process oriented.	There is a restricted flow of information and ideas to broader community. There may be a low degree of user access. A short-term result mind set, ofte limited to current and local capabilities, is created by near-term profit goals. There are relatively hig personnel and sunk costs, and consequent barriers to investment in high risk, speculative ideas.

Of course these characteristics can at best be construed as true in general, with many individual exceptions. There are individual universities, or laboratories, or individuals within them, who are very good at rigorous project management, even though this is not a general strong point of universities. Similarly there are industrial laboratories, or individuals within them, who have excellent records of long-term basic science vision and open exchange of scholarly views. The universities, national laboratories, and industrial and private not-for-profit laboratories each include extremely diverse settings, working climates, and individuals. No intelligent policy could treat them as if they were uniform entities of completely predictable characteristics.

One purpose, and perhaps the only purpose, of looking at these general characteristics but then noting the strong probability of exceptions, is to emphasize a key point: the real issue is not the theory of optimal organization but the accomplishment of a purpose. Given a purpose, the organizations participating can be chosen based on their actual and individual capabilities to accomplish the goals. This viewpoint considers the materials research program not as "pie" to divide, but as a project to do. In a climate of the growing politicizing of science this may sound like a naive statement, but my observations tell me that the opposite approach is also naive and doomed to failure in political gridlock.

The best use to be made of the generalities about the

various research establishments is to alert program administrators of the need to compensate for certain risks and be aware of special opportunities, not to lock them in to one structure or another. For instance, in investing in university programs the risks are clearly that there may be lack of focus on a central purpose such as bringing materials R and D into economically useful application. Needed cooperation among departments or disciplines may be blocked by campus politics or traditions. Attention to schedules and interfacing with the outside world may be blocked by important other concerns, such as educational demands. In some cases certain needs of an advanced materials development program may have little educational value, may require pervasive secrecy, and therefore may be entirely inappropriate for campus work.

Similarly, programs at national laboratories may become enmeshed in intra- or inter-laboratory politics, or faddish maneuvers to attain the best position in a highly politicized budget process. Volatile actions stemming from that budget process may disrupt continuity and demoralize staff. Program goals may be lost in the fascination with, or budgetary needs of, large complex facilities.

Relying on industrial research has its own risks. Strong short-term performance demands may lead to a pattern of "skimming the cream" from current materials technology instead of building a strong and continuously self-renewing infrastructure of new basic knowledge, trained people, and

research facilities. Short-term career and economic incentives may distort projects away from sustaining vision and toward narrow, near-term self interest. Similar narrow interests may limit activity aimed at exchanging and actively developing new ideas in all their ramifications and applications.

However, for all these risks of each performer, which I've stated perhaps too frankly but I believe fairly, each presents opportunities and strengths. The point is to be wary of these realities, to use common sense to compensate for the obvious weaknesses, but still to go forward using the strengths of each as they best fit pragmatically with particular goals of the materials program.

I'd like to turn now completely away from generalities to specific examples of how these principles can be applied in practice. We have an especially useful and relevant experience in Ohio, in the forms of the Thomas Alva Edison Innovation Program, (Appendix 3) stimulated by the same economic pressures which created Pennsylvania's Ben Franklin program and similar efforts in other states. The Edison Program administrators had to face the same key questions with which I opened this paper: engineering vs science, "big" vs "little" science, planned vs opportunistic programs, and determining the optimal mix of performers. Within the state, as in the nation, the private and state universities, independent research laboratories, industrial facilities, and state agencies tend to look covetously on each other when a major State commitment is planned. As we'd all expect,

there was no magical way to resolve these tensions, and even well into the program we frequently sense them. However, by acting in a pragmatic, flexible, and goal and results-oriented approach, the State has so far been able to capitalize on the diversity rather than be frustrated by it. One basic technique to build truly cooperative relationships between industry and university interests was to require industry matching commitments to State research funds, which resulted in a variety of consortia and joint planning panels. Similarly, the State made clear that it would not entertain individual efforts from closely related or complimentary institutions, and in fact expected such institutions to form consortia that used their various capabilities synergistically. The State did not dictate in detail the nature of the industrial commitments, or the form of the consortia arrangements between cooperating institutions, but it did refuse to allow itself to be drawn into pie-dividing disputes among the parties, and it set out clear principles of expected cooperation and communication among them. The actual arrangements to fulfill those principles are diverse and imaginative, and probably represent a much richer organizational pattern than could ever have been written into law or administrative regulation. I can say first-hand that our own university, a participant in three of the States seven Advanced Technology Application Centers, has found itself prodded into forming cooperative relationships which are entirely logical and beneficial from public policy and scientific viewpoints. Yet they have existed

only in the realm of dreams and intentions for many years, blocked by many forms of bureaucratic and institutional inertia. The State's external pressure was needed to move us to forming the needed linkages, and yet it was applied with sufficient pragmatism, flexibility, and intelligence that we could act creatively and innovatively.

The current National Science Foundation Engineering Center program is at an early stage, but is having similar impacts, especially in stimulating on-campus coherence and results-oriented management. NSF has not demanded any particular form of multidisciplinary or inter-institution cooperation, or innovative forms of management. However, it has made clear that evidence of creativity and boldness in network-forming is just as important as local scientific credentials in the competition for support. On our own campus this has already created some interesting network-forming even to plan our proposals. As in the Edison program the competition to show success in creating synergies among resources and tasks has helped overcome the bureaucratic and individualistic tendencies that often block or inhibit these.

In some cases highly promising networks already exist for materials research, but the capabilities are not really used. Several of the national laboratories have groupings of associated universities; the Oak Ridge Associated University network of over 50 southeastern schools being a prime example. Taking those networks from a state of loose affiliation to

a state of dynamic synergistic partnership takes a real investment in time and organizational effort. In the short-term, as we often feel in our Ohio Edison program relationships, the investment seems to be more effort than it's worth and the pay-off a long way distant. Yet it is networks like the ORAU-Oak Ridge National Laboratory group which show the way toward ending the wasteful back-biting competition between the various kinds of performers. In the long-run, we're wasting much more time and effort on the kind of political maneuvering going on for the "spoils" of materials and other technical programs than even the admittedly arduous networking-forming would take.

A competition under guiding general principles is only one example of a mechanism to achieve networking and broad program goals. The Defense Department for years has been able to strategically plan for basic technology development in areas of concern to it, and move rapidly and decisively to nurture and link these in non-competitive programs. A key feature of this capability, however, has been a generally very high level of expertise <u>within</u> the Department concerning the technology in question and the performers available. This capability is not always present in specific areas in civilian agencies, and directed, non-competitive programs run grave risks of total inappropriateness under those conditions.

Negative lessons abound as well, of course, as warnings of what to avoid. For several years I have been involved in an international innovation management study comparing

approaches in the U.S., east and west Europe, the Soviet Union, and Japan. In some cases in this study we have seen the results of very rigidly planned allocation of resources to specific institutions or performers for specific kinds of tasks. The result is often enormous investments and capabilities mobilized at specific points in the innovation chain (huge 3000 person technical institutes, etc.) but forbidding gaps and barriers in moving ideas along this chain. The result is also often a history of missed opportunities, because the focus on organizational structure among performers overwhelmed the more appropriate attention to a pragmatic networked approach to getting the task accomplished.

The international study has highlighted two other points. One is that we are blessed with some real advantages in this country concerning the ease, in principle, of interchange among our institutions performing research and development tasks. The rapidly growing informal exchanges of ideas and personnel between industry and universities in the U.S. is without parallel anywhere else in the world. Similarly, the association of the great national laboratories with university consortia is a management innovation which gives us a foundation on which to build unique working relationships. We are fortunate in this country that we have not built up the kind of institutional barriers that exist in many countries between the academic, industrial, or national academy laboratory communities. We have indeed grown slack in making the effort to form groupings, or have let narrow self-interests

draw us into resource rivalry instead of cooperation, but we do not have the historic barriers that so many countries must deal with.

The second observation from the international study concerns the wisdom of cooperation across international boundaries in order to take advantage of the unique skills or facilities in various nations. As one observes international innovation strategies it is clear that history, national culture, institutional momentum or unknown factors have for some reason catapulted some countries far ahead of others in specific areas. Design may be the hallmark of one country's effort, quality or labor relations that of another. It is clear looking at these situations that though head-to-head competition may be helpful or necessary in some cases, in others it is a far wiser course for each nation to invest in its own areas of excellence and try to learn from others or share resources in those areas which are not natural strengths. The parallels in materials research are obvious. Much is being written about European excellence in neutron facilities, as one example, with urgent alarms for the U.S. to match them. Many researchers with whom I speak, however, point out that our own strengths are in different areas, and they see no sense in playing catch-up in an approach that is not a main focus of interest here. For these, the travel to even a European facility once a year or so is a relatively small expense compared to other research costs, and in many ways they are glad that another

country is willing to invest in the construction and maintenance of resource so that our own budget has more room for areas of greater interest here. It is clear of course that we cannot allow ourselves to become parasites or beggars for research facilities. Each issue should be judged on its merits, however, not with an automatic assumption that we must invest to be the best in every sub-segment of the field or facilities of materials science. I'm stressing, then, an extension of the network concept: certainly among our own performers of materials R&D, but extending to the international arena if useful. Once again I come back to the point of looking at the goals or tasks we want to accomplish, not at a theoretical relationship of organizations or sets of facilities.

As a summary, I will stress again the viewpoint that any set of roles for the various R&D performers must be considered pragmatically in terms of individual capabilities and energies for real tasks, not in terms of generalities or constituency politics. More important than the starting point of the organization structure will be an attitude of viewing it as an experiment, with serious evaluation of results, and commitment to change if indicated. I believe that a constant perspective of task-orientation, as opposed to pie dividing, will make the politics of evaluation, feedback, and adjustment much more feasible than might be expected. The MRL system may be an example of one mechanism

needing serious evaluation and mid-course adjustment, the large facility system another. Though conventional wisdom often cites fixed-interest resistance to any changes of roles, my experience tells me that even in an existing network like that of the MRL's many of those in leadership positions would like to come together for serious thought on how the system can be better organized to meet national and local goals. If there is a perception that the idea of evaluation and change is being promoted merely as a tactic of adversaries in a pie-dividing exercise, we can be sure there will be resistance and lack of substantive thinking. On the other hand, everyone enjoys reaching excellence and being part of an organization that reaches for the best. If our evaluations and adjustments can follow the task-oriented model in this spirit, I believe we can reach the goal of fully mobilizing our research and development talents for leadership in materials science and applications in the coming decades. It will be a robust, mutually re-inforcing and flexible network of our centers of excellence and talent in materials science and engineering which will lead to that excellence, certainly not a set intriguing competitors in a world of budgetary politics.

APPENDIX I

10/7/80

To Plan or Not To Plan: U.S. Science Policy Debated

SANTA BARBARA—The question of an American "science czar"—a person who would be responsible for the long-range planning of basic and applied science—has been raised again. Carroll W. Pursell, Jr., University of California, Santa Barbara professor of history who specializes in American technology, testified on the subject before a U.S. House of Representatives subcommittee this past summer.

Pursell was asked specifically to discuss science planning under the New Deal by the Subcommittee on Science, Research and Technology chaired by Representative George E. Brown, Jr. (D-Calif). The UCSB historian has written and lectured on the state of science during this period.

The subcommittee held four days of hearings "to find out what has been done to insure the health of science and technology through longer term planning."

The attitude toward science during the 1930s, said Pursell, was essentially a reflection of the ebb and flow that has existed since the early days of the Republic.

The twin poles of centralism and pluralism have tugged at American science throughout the course of the country's history, he added.

The idea of a cabinet-level Department of Science, first discussed intensively in the 1880s, was introduced again in Congress in 1935—this time as a Department of Science, Art and Literature. Celebrities from the humanities supported the idea, but scientists tended to oppose it, Pursell said.

Although the idea of a powerful federal agency was not realized during the 1930s, specific areas did have some success in scientific planning, the UCSB historian said. The Department of Agriculture under Henry A. Wallace, for example, was described by Pursell as "the most scientifically literate of Roosevelt's new cabinet officers."

Largely through Wallace's efforts, legislation was passed in 1936 authorizing annual expenditures for fundamental research into agriculture and also the building of regional laboratories.

Despite isolated successes, the goal of centralized planning was abandoned and replaced by the use of the appropriations process. As Pursell told the committee, "Planning had constitutional problems which mere appropriations did not."

Even though the federal government has shown that it can mobilize toward a central goal—as illustrated by the American aerospace effort after the USSR had launched Sputnik in the 1950s—Pursell said that this kind of "fine-tuning" can lead to problems. Once America had achieved its space goals, at least momentarily, and the momentum had slowed, he said that a problem arose over what to do with facilities as well as manpower developed for the program.

Pursell believes that the tug-of-war between centralists and pluralists will characterize the course of central scientific planning.

The most notable difference between 1980 and the 1930s, he contends, is that government subsidies to scientific research are now much larger, giving the federal government more clout.

The federal government, Pursell testified, will continue to make policy in scientific research through the work conducted by its own agencies—such as the National Bureau of Standards and NASA. It will do so through research grants to industry and the universities. The third major area of research, the privately funded sector, is likely to remain beyond government control, because, as Pursell said, "There is always tremendous opposition to public attempts to plan what are seen as private activities."

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European Synchrotron Choice Draws Protests

Selection of Grenoble by the French government is viewed as a political decision; some nations complain they have been excluded

Strasbourg. The French government has been hit by a fierce storm of protest over its decision to propose the city of Grenoble in the French Alps as the site for the construction of the European Synchrotron Radiation Facility (*Science*, 2 November, p. 524).

A recent visit by President François Mitterrand to the region of Alsace was boycotted amid nationwide publicity by virtually all local politicians, who claimed that the government has broken a promise to back the rival candidacy of Strasbourg, situated on the border between France and West Germany, as the site of the new machine.

Two days previously, representatives from Scandinavian countries attending the annual assembly of the European Science Foundation in Strasbourg had registered their own protest at the way the French and West German governments appear to have preempted formal consideration of site proposals from smaller European countries. By agreeing jointly to support the Grenoble proposal and to provide 60 percent of the funding, France and West Germany have virtually guaranteed that the proposal will be accepted. It will be a $200-million facility that will use the hard x-rays given off by accelerating electrons to study the structure of both organic and inorganic matter.

The announcement that the French government had chosen Grenoble rather than Strasbourg to host the facility was made in mid-October by Louis Mermaz, the leader of the majority socialist party in the National Assembly. Both science and politics seem to have played a part in the decision. Indeed, uncertainty about the relative weight given to these two factors largely explains the controversy that continues to surround the outcome of several years' intense discussion.

French research minister Hubert Curien said at the meeting of the European Science Foundation (of which he has been the president for the past 4 years) that one reason for choosing Grenoble was that the synchrotron would be placed adjacent to the high-flux neutron reactor run by the Institut Laue-Langevin (ILL), and would thus be in a good position to make use of the institute's existing technical and administrative infrastructure.

This reasoning was endorsed by Harry Atkinson, director of the science division of Britain's Science and Engineering Research Council, even though he added that Britain (which finances the ILL jointly with France and Germany) was not currently in the position of being able to put any money into the new project.

Few observers have failed to comment, however, on the fact that Grenoble lies in the center of the region represented by Mermaz in the National Assembly, and that the socialists are keen to reverse the loss of the city to the conservatives in last year's municipal elections after almost 30 years of socialist rule.

It is also being pointed out that although the choice of Strasbourg was strongly lobbied for by the National Center for Scientific Research (CNRS), which had hoped to see the facility become the center of an entirely new international research institute, Grenoble's case had the backing of the powerful Atomic Energy Commission, the current landlord of the ILL.

> Denmark and Italy may decide not to provide any money for the project.

Whether or not political factors such as these played a major role in the final decision, their very existence is being skillfully exploited for maximum effect by those who would still like to see the machine go to Strasbourg (as well as those with other reasons for wishing to embarrass the socialist government).

Local politicians, for example, backed by many local university and CNRS scientists, had long been hoping that the construction of the synchrotron in Strasbourg would become a symbol for the economic and technological renaissance of a region that currently has a 15 percent unemployment rate. They claim that the government supported this strategy in a "planning contract" signed with the regional council in April, in whose annexe it says that the French government will propose Strasbourg to its European partners as the site of various joint projects, including the synchrotron facility.

Although the government now says that this was merely a statement of intent rather than a binding legal agreement, this interpretation is being contested by local political groups—particularly those aligned at a national level with the conservative opposition—who are using the affair of "our synchrotron" to symbolize their broader opposition to the government's policies.

In scientific circles, those who remain critical of the decision and the way it was made are focusing their objections around two points. The first is the suitability of the Grenoble site, which is located near the center of the city on land squeezed between two main roads and adjacent to the river Vrac (Strasbourg had made the more scientifically attractive offer of a virgin site on the city outskirts).

Some are questioning the likely impact of heavy vehicles moving past, suggesting they could affect the quality of observations. Others point out that although the site being offered is just able to accommodate the synchrotron in its current form—a ring 770 meters in circumference—there would be no room for the addition of major new facilities if these were felt to be needed in 10 or 15 years time.

In reply to the first criticism, Brian Fender, the current director of ILL who was largely responsible for Grenoble's bid for the facility, says that a survey carried out over the summer by the Atomic Energy Commission suggested that outside disturbances were not significantly greater than the tolerances suggested by the synchrotron's design team. Fender also points out that nearby sites could be used for later expansion, and that the suitability of these is now being studied both by the Atomic Energy Commission and the CNRS.

The second focus of criticism concerns the way that the decision to back the Grenoble site was taken by France and West Germany after little consultation with other European nations. Anger has been expressed particularly strongly by Denmark and Italy, both of whom had promised substantial government support for their own site proposals for the facility, in Risø and Trieste, respectively (*Science*, 27 July, p. 391).

APPENDIX II

Materials Science and Engineering

Ability to compete in high technology will be an important determinant of success in the competition between nations and regions. In turn, success in technology is crucially linked to leadership in materials science. The development of new or improved materials permits the creation of new technologies, better quality control, less costly products, and, in some instances, less dependence on imports of scarce elements. To advance materials science requires close collaboration of physicists, chemists, and engineers. Laboratory experimentation is stimulated by theoretical physicists or chemists. Scientific advances also come as a result of stimuli generated by engineering needs. Interesting developments in materials science are occurring; some of these are portrayed in this issue of *Science*.

For the most part, the chemistry of the substances available for use as materials is well known. However, the behavior of substances at surfaces and interfaces is not well understood. Microstructures, both in the interior and at the surface, can have a large effect on properties. One method of markedly altering a surface is ion implantation, which is widely used in the semiconductor industry. It is also increasingly being used in other applications to provide surfaces that differ radically in composition from the bulk of an object. Intense, but short-period, laser irradiation can almost instantaneously melt a shallow layer at a surface; this is followed by a comparably fast solidification. This treatment can freeze into place microstructures with superior resistance to friction, wear, and corrosion. Laser treatment of engine parts is now widely used in the automobile industry.

Research on the surficial interactions between living tissue and prosthetic devices has led to potentially improved performance of the millions of implants that are done each year. Particularly useful are glasses or ceramics containing some calcium phosphate. At the surface of the prosthetic device in the presence of body fluids, hydroxyapatite is formed. Cells recognize this substance, are compatible with it, and form connections to it.

In many applications, engineers seek materials that maintain their tensile strength at high temperatures and that are resistant to corrosion. Many of the alloys now in use contain imported chromium as an essential constituent. Research reported in this issue discusses the properties of Ni_3Al. Ordinarily this intermetallic alloy is brittle and unworkable. However, with the addition of boron (200 parts per million), it becomes ductile. Its strength actually increases with temperatures up to 900°C, and it is comparatively free from corrosion.

Plastic composites seem destined for very large-scale applications in the aircraft and automobile industries. Already one manufacturer of airplanes has announced a new model to consist largely of plastics. There will be great savings in weight as well as fewer parts to assemble. A large fraction of the Pontiac Fiero will consist of composites. Intrinsically, some polymer molecules are extremely strong. To use them advantageously requires a knowledge of their behavior during processing. Once strong fibers are formed, composites may be created to meet engineering specifications.

Two of the articles in this issue describe theoretical studies and research aimed at revolutionizing computers and data transmission. The impetus for part of this work comes from the successful development of optical means of communication with the use of glass fibers. It also is based on the development of lasers that are capable of delivering extremely short pulses. In principle, computers based on photon processing could operate much faster than the current semiconductor devices.

Efforts to advance materials science will continue to be driven by opportunities and international competition. Students who have an aptitude for the physical sciences and a desire to participate in research with obvious payoffs in meeting societal needs will find work in the materials sciences rewarding.—PHILIP H. ABELSON

editorial

Needed: more materials research at universities

Nature combined many forces to engineer and produce the manifest universe. Man has sought to understand these forces and their interplay so as to explain and manipulate the world around us. The drive to do this has been provided not only by our innate curiosity to explore and discover truth and its beauty but also by our need to improve our well-being. We tend to call the understanding of nature science and the application of scientific or empirical knowledge technology. This compartmentalization into science and technology has served us well and will probably continue to do so in the future.

There are, however, a few very broad areas of technical endeavor where such a division is at best blurred and where scientific knowledge is almost immediately translated to technological know-how and where the technology leads to questions that science cannot as yet answer. This ferment, which is rich in intellectual content and potential for application, is characteristic of research relating to high technology. As such, it affects the quality of life and the economic power of each nation directly.

Two examples that come to mind are research in materials and medicine. Whereas it is easy to relate to the need for placing resources in medicine—we can all personally relate to pain, disease and mortality—our appreciation of the need for materials research requires some reflection. Consider, for example, computers and telecommunications, a single interwoven industry. Their ubiquitous presence and vital role in our society are undeniable. Their economic role—together they will be a trillion-dollar business by the end of this decade—in world affairs can hardly be ignored. Even though the industry has been characterized by spectacular progress in technology, it is evident that continuing progress in hardware will almost completely depend on our ability to control the properties of materials. This hardware, such as the transistor on a VLSI chip or the macroscopic package used for housing these chips, is built by the addition or removal of appropriate materials in well-defined geometrical and spatial arrangements. Complexity in manufacturing VLSI devices is almost entirely associated with the shrinking of the physical size of materials—from micron to submicron dimensions. Knowledge about the properties of metals, polymers, ceramics, semiconductors, insulators and their composites in restricted dimensions is required. Knowledge about interfaces between these materials is necessary. Knowledge about the microscopic mechanisms of growth or removal of atoms or molecules from surfaces is essential for developing alternate processing technologies. These are only a few general observations. The list describing areas where scientific knowledge is needed is long. It is my belief that the lead in hardware could go to those that can best marshal their resources in materials sciences.

Yet at our universities research in materials related to the electronics industries is far from adequate. There are many factors responsible for this, among them that industry has not effectively communicated its needs, that research in this area can be expensive and that help from industry or government is inadequate to nucleate a number of new activities with proper equipment and infrastructure. However, given the unusual interdisciplinary and science-technology character of materials research, the nation's universities, industrial laboratories and funding agencies need to work together so that the multifaceted capability of our university research establishment can be brought to bear in this important area both to generate new information and to train experts. This cooperative effort must take place, not only to assure industry's lead in tomorrow's technology and the well-being of the nation, but, more fundamentally, to assure that future work in materials research by scientists and technologists will proceed in natural harmony and on a self-sustaining basis.

PRAVEEN CHAUDHARI
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Major Materials Facilities Ranked

An unusually tight-lipped committee of the National Research Council has released a report calling for the expenditure of up to $900 million for new and upgraded materials research facilities, including instrumentation, over the next 12 years.* One reason for the secrecy: the committee headed by Frederick Seitz of Rockefeller University and Dean Eastman of IBM's Yorktown Heights Laboratory listed its recommendations in order of priority; that is, which should be funded first.

The rankings are for "major" facilities, defined in the committee's charge as those costing $5 million or more. The biggest ticket items are new sources for synchrotron radiation and neutron scattering research, whose price tags in the report range from $160 million to $330 million. All told, eight of the nine recommendations deal in one way or another with these two areas of research. The ninth is for a $5-million upgrade of the National Magnet Laboratory, a center for the production and use of ultrahigh magnetic fields at the Massachusetts Institute of Technology.

Presidential science adviser George A. Keyworth, II, asked for the study last fall and requested that findings be ready in time to serve as input for the fiscal 1986 budget preparations. One other function of the materials facilities study is the repair of the various lines of communication that were damaged or ruptured during the NCAM (National Center for Advanced Materials) affair (*Science*, 21 October 1983, p. 308).

To be established at the Lawrence Berkeley Laboratory with a synchrotron radiation source as its centerpiece, NCAM was inserted in the fiscal 1984 budget at Keyworth's insistance with little of the customary peer review. Some in the materials research community were particularly outraged and said so. Congress funded only a reduced CAM (without the National), and the synchrotron light source is in abeyance.

Although Keyworth specifically asked that the major materials facilities committee not wrestle with the highly charged issue of *big* versus *little* science, there were a number of advocates of the latter viewpoint in the group. Ideally, the report will therefore be read as a statement of what the materials community will come together and support. "It was a big accomplishment to get them all to walk out of the room together," noted one observer.

Prior to its recommendations, the committee listed two prerequisites to any new facilities: that "they are accompanied by expanded support of smaller materials research programs, including related instrumentation," and that "resources must be provided to operate existing user facilities productively." The latter proviso has already been violated as congressional action on DOE's fiscal 1985 funding will negatively affect the availability of both synchrotron radiation and neutron scattering beam time.

The committee then divided its attention between "new large facilities" and "new capabilities" at existing facilities. Priorities were established separately in each category. Synchrotron radiation and neutron scattering compete with one another for funding, and the recommendations give the impression that the committee paired off a new facility for one with an upgrade for the other. However, the recommendations do parallel closely those of two recent reports, one on each of the two fields.†

For example, among the large new facilities, the highest priority went to a $160-million synchrotron x-ray source based on a 6 billion electron volt (GeV) electron storage ring. Exceptionally bright beams of "hard" (short wavelength) x-rays would be produced by wigglers and undulators, special magnets inserted into the storage ring that bend the electrons into a sinusoidal trajectory and thereby greatly enhance the emission of synchrotron radiation. The committee urged an immediate start on design, so that operations could begin by 1992. The Europeans are close to approving a similar machine (*Science*, 27 July, p. 391).

On the new capabilities side of the ledger, the committee gave its highest ranking to guide halls and new instruments for the existing reactors at Brookhaven National Laboratory and the National Bureau of Standards, which have "cold" neutron sources. Cold or very low energy neutrons are especially valuable for certain types of experiments, and the United States woefully trails Europe in their availability. Guide halls use the neutron equivalent of light guides and thereby maximize the sparse neutron flux. Since it will be 12 or more years before a new steady-state source could be ready, upgrades such as this are essential to keeping U.S. neutron researchers within sight of the competition overseas. Cost is $30 million at each laboratory.

Similarly, the second new facilities ranking was given to a $260-million advanced steady-state neutron source, while the second new capabilities priority went to additional insertion devices for existing synchrotron radiation sources at a total cost of $20 million. The neutron source would provide at least five and possibly ten times the neutron flux as the best existing U.S. reactors. In particular, it would cover the entire range from thermal to cold neutrons.

Continuing the pattern, the committee gave a lower energy (1 to 2 GeV) synchrotron radiation source of the type proposed for NCAM the third priority. The $70-million machine would generate vacuum ultraviolet light and "soft" (long wavelength) x-rays. Meanwhile, an experimental hall and instrumentation for a pulsed neutron source now under development at the Los Alamos National Laboratory, at $15 million, came in third on the new capabilities list.

The pattern broke down for the final selections. The last new facilities recommendation was a $330-million high-intensity pulsed neutron source. Pulsed sources are based on proton accelerators. This one would generate ten times the flux of the Los Alamos source and the go-ahead on the advanced machine would await results from there.

Rounding out the new capabilities, the magnet lab upgrade was fourth. And new targets to increase neutron fluxes from the pulsed sources at Los Alamos and Argonne National Laboratory were fifth on the list.

The committee concluded the entire set of recommendations minus the pulsed neutron source could be financed for $50 million per year over the next decade.

—ARTHUR L. ROBINSON

**Major Facilities for Materials Research and Related Disciplines*, available from Commission on Physical Sciences, Mathematics, and Resources, National Research Council, Washington, D.C. 20418.
†*Planning Study for Advanced National Synchrotron Radiation Facilities* (Office of Basic Energy Sciences, U.S. Department of Energy, Washington, D.C., 1984); *Current Status of Neutron Scattering Research and Facilities in United States* (National Academy Press, Washington, D.C., 1984).

APPENDIX III

OHIO NEWS

TRENDLINES

Ohio gambles $47 million to "ATAC" the job problem

Ohio's Development Department, nine schools, and more than 40 companies are wagering about $47 million on the establishment of six Advanced Technology Application Centers (ATACs) around the state. The hoped-for payoff from that investment: the eventual creation of new jobs for Ohioans.

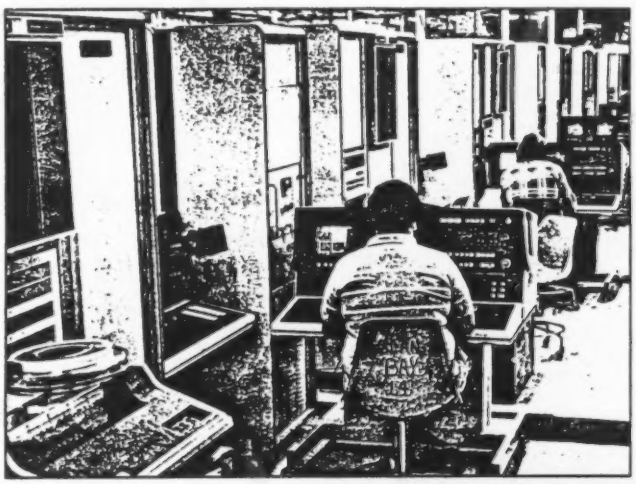
Funding for the ATACs comes from $23.6 million in state grants, and matching funds from the participating corporate partners. The state money comes from the Ohio Development Department's Thomas Alva Edison Partnership Program, an initiative of Governor Richard F. Celeste's administration which is designed to encourage state economic development through technological innovation.

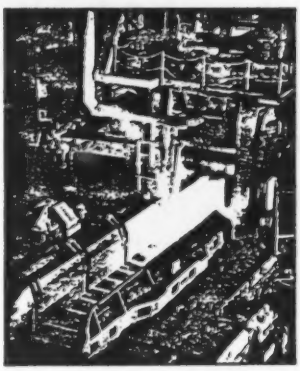
"The challenge we face in putting Ohioans back to work depends on our success in using this state's scientific and technological resources to bring new technologies off the shelf and onto the shop floor," Celeste said in July at one of a series of press conferences he held around the state to announce which ATAC proposals the state had decided to fund. "Each ATAC represents a partnership among education, private enterprise, and this administration to build on our existing technological strengths and thereby create the jobs of the future."

In all, the state received funding requests totaling $62 million from 13 groups interested in starting ATACs. Those proposals were reviewed by independent panels of scientific and management experts, who recommended backing six of the applicants. Those recommendations were then ratified by the Industrial Technology and Enterprise Advisory Board, which oversees the Edison program.

The six projects approved are:

- The Institute of Advanced Manufacturing Sciences at the University of Cincinnati, which got a $4.1 million state grant. Other participants in the institute are the Cincinnati Technical College, Cincinnati Milacron, Kroger, Battelle Memorial Institute, General Electric's Aircraft Engine Group, Procter & Gamble, and Surgical Laser Technologies Inc.
- The Ohio Welding Research and Development Institute at Ohio State University in Columbus, which got $4.1 million in state funding. Also involved in that effort are the Columbus Technical Institute, General Motors, IBM, TRW, General Electric, Cincinnati Milacron, Hobart, Deere, Caterpillar Tractor, Westinghouse, and Bishopric.





Goal of the program is to create more high tech jobs and reduce the state's dependence on heavy industry. Workers, above, are testing scanner systems at Johnson & Johnson Co.'s Technicare Corp. unit in Solon.

- The Cleveland Advanced Manufacturing Program, a joint effort of Cleveland State University, Case Western Reserve University, and Cuyahoga Community College that received a $4.1 million grant. Also involved are White Consolidated Indus-

OHIO NEWS

tries, Reliance Electric, TRW, Allen Bradley, Eaton, Parker-Hannifin, Bailey Controls, and Cleveland Pneumatic.

• The Recombinant Animal Biotechnology Center at Ohio University in Athens, which received $3.1 million in funding. Also participating are OSU's Agricultural Research & Development Center, CWRU, the Ohio Farm Bureau, and Embryogen Inc.

• The Advanced Technology Application Center in Polymers, a joint effort of the University of Akron and Case Western Reserve University, which received $4.1 million. Industrial sponsors of this ATAC are Cabot Corp., Dow Chemical, Ferro Corp., Firestone, General Tire and Rubber, BF Goodrich, Goodyear, Glidden/SCM Corp., Lubrizol Corp., Monsanto, A. Shulman Inc., Sherwin Williams, Sohio, and TRW.

• The Applied Information Technologies Research Center at OSU, which got $4.1 million in state funding. Also taking part in this effort are CompuServe, Chemical Abstracts Service, Banc One, BancOhio, Battelle, and Online Computer Library Center.

Governor Celeste announces the polymer center grant in Akron, one of six efforts to move technology "off the shelf and onto the shop floor."

Ohio is not alone in starting up such technology application centers. Several other states, including Virginia and Tennessee, have recently launched similar efforts. Nonetheless, it appears Ohio's ATACs are unique both in the size of their funding and their scope of operations.

"As far as I know, [Ohio's] is the largest such grant ever made by a state for technology application," declares Miles Friedman, executive director for the National Association of State Development Agencies. "Three other features of the program would also seem to be particularly innovative — the use of matching funds, the emphasis on the practical application of technology, and the suitability of this program to the current industrial mix in both the state and the region." ■

By Matthew Hall

Quit stalling.

If you're not sure you're getting the attention you *think* you deserve from your present accounting firm, then maybe it's time you let Wiley, Distelhorst & Co. do your thinking for you when it comes to financial statements, tax returns, tax planning, pension and profit-sharing and comprehensive financial planning. Quit Stalling. If you *think* you're not getting personal service...you're not...and you're still stalling...call Wiley, Distelhorst & Co.

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THOMAS ALVA EDISON

PARTNERSHIP PROGRAM

T H O M A S A L V A E D I S O N

The Thomas Alva Edison Partnership Program was created by the initiative of Governor Richard F. Celeste to encourage state economic development through technological innovation. The $32.4 million Edison Program provides matching funding to foster cooperation research and development efforts involving businesses and educational institutions that lead to the creation of jobs in Ohio.

The Edison Program operates through the Ohio Department of Development. The Industrial Technology and Enterprise Advisory Board (ITEAB), a bipartisan advisory board consisting of two legislators, and seven private citizens appointed by the Governor, assists the Director of the Department of Development in administering this program.

The Edison Program comprises three separate initiatives:

[redacted]

This program provides matching funds to support cooperative university/industry joint technical research and development activities. Funded research projects must involve an industrial co-sponsor(s) and a researcher(s) associated with an Ohio public or private institution of higher education. The industrial co-sponsor(s) must maintain or propose to maintain a relevant business facility in Ohio and make a contribution to the project at least equal to that requested from the State.

Two types of funding will be available:

Class 1:
Early Stage Feasibility Research:

Proposals in this class will be directed toward determining the technical feasibility for commercialization of ideas. Such a project might involve feasibility-related experimental or theoretical research on an innovative idea. This may include investigations at the cutting edge of technology directed at the development of new processes or systems. Funding for this type of research in the form of grants will be available in amounts up to $50,000. Normally, the research period should not exceed 12 months.

Class 2:
Advanced Applied Research:

Proposals in this class should result in measurable technical objectives such as the development and refinement of a laboratory prototype, if possible, or functional specifications. Proposals in this class will deal with the application of technology and development of proven concepts toward commercialization. Funding for this type of research in the form of risk capital will be available in amounts up to $250,000. The State will seek a return on such funding standardly in the form of a royalty arrangement. Normally, the research period should not exceed two years.

Each proposal will undergo a technical review as well as an analysis of the market for the resulting product or process. There is no deadline for applying for funding. Applications will be considered on a rolling basis, with awards announced each month. Processing is expected to take from 10 to 12 weeks. Copies of the IRFP guidelines are available upon request; application forms may be obtained after the applicant has reviewed the guidelines and contacted the Edison Program staff to discuss the proposed project.

P A R T N E R S H I P P R O G R A M

Through this program, the State is providing matching support for the formation and growth of six technology research, development and implementation Centers located around the State. The Centers chosen are:

Institute of Advanced Manufacturing Sciences (IAMS)

Funded for $4.1 million, IAMS, through the University of Cincinnati and related businesses, has set its primary objective as improving overall manufacturing operations and profitability. The initial technology focus includes manufacturing systems analysis, automated equipment development and integration, measurements and control, and laser technology.

Edison Welding Institute (EWI)

Funded for $4.1 million, EWI, through Ohio State University and related businesses, will improve the use of welding technology in manufacturing. The institute will provide a wide array of services, and be comprehensive in scope, carrying out research, development, applications engineering, education/training, and technology transfer.

Center for Advanced Manufacturing Program (CAMP)

Funded for $4.1 million, CAMP, through Case Western Reserve University, Cleveland State University, Cuyahoga Community College, and related businesses, will perform "world-class" research and development in advanced manufacturing technology, establish high-quality advanced manufacturing technology training, and transfer advanced manufacturing technology information and capabilities to local industries.

Edison Polymer Innovation Center (EPIC)

Funded for $4.1 million, EPIC, through the University of Akron, Case Western Reserve University, and related businesses, will develop new polymer technology that can be brought into commercial use in the form of new industrial products and processes.

Edison Animal Biotechnology Center (EABC)

Funded for $3.1 million, EABC, through Ohio University, Case Western Reserve University, Ohio State University, and related businesses, will apply new genetic engineering technologies to improve the profitability of Ohio's livestock agricultural sector and to create new rural economic opportunity.

Advanced Information Technology Research Center (AITRC)

Funded for $4.1 million, AITRC, through the Ohio State University and related businesses, will create new technologies that will provide rapid availability of information in the office, school, and home. AITRC research programs include information processing, software engineering, microelectronics, systems engineering, and telecommunications.

Participating private sector firms must at least match the State's commitment, which pushes the total investment in these Centers to at least $47 million. The matching of funds helps to insure the relevance of a Center's activities to Ohio industries.

The review process undertaken for the selection of the Centers began in April, 1984 when thirteen applications were submitted to the Industrial Technology and Enterprise Advisory Board (ITEAB). Each proposal received two independent reviews—a scientific technology review and a management review.

Both review panels consisted of nationally recognized individuals from outside the State of Ohio selected by the National Science Foundation, the National Institute of Health, and other groups. Conducted essentially as a peer review process, the science and technology review panel, consisting of nationally eminent scientists for each technological focus represented in the ATAC applicant pool, evaluated the scientific and technological strength of each applicant. The management review panel members, drawn from industry, academia, and government and experienced in large-scale university/industry cooperative research and development efforts, evaluated the organizational structure of each proposed Center. These critical appraisals were presented to ITEAB which made the final recommendations.

Criteria for selection included the demonstrated capability to be or become a national or international leader in one or more technology areas; the extent to which the technological focus was based on that region's existing strengths and resources in both the academic and private sectors; and the ability of the Center to show how its program will help create jobs in Ohio, stimulate the start of new technology businesses, help existing businesses become more competitive, and attract expanding out-of-state and foreign businesses. A critical element in each Center's research and development strategy will be plans for the transfer of innovative technological developments to the private sector for these purposes.

State funds to a Center will be phased in over time. Centers will be expected to meet pre-established performance criteria and to become self-supporting within five years.

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Thomas Alva Edison
Partnership Program
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State of Ohio, Richard F. Celeste, Governor | Department of Development, Alfred S. Dietzel, Director

Innovative Technology Search

The Search Program is designed to help establish an organized and ongoing structure within participating universities and colleges that will identify, evaluate, and document the commercial potential of their technological assets. This program will provide matching funds and assistance to certain interested educational institutions in Ohio to encourage the eventual transfer of these newly-recognized technologies to the private sector for the start-up of new businesses or as additions to the product lines of established firms.

Conducted on a Statewide basis, the Search Program seeks to accelerate the rate of innovation by identifying both technological opportunities and market needs in a way that allows these elements to be matched. This means that, for the first time, businessmen in Ohio will be able to ascertain if and where Ohio has the right technology to solve a problem; potential investors will be able to locate a group of related technologies worthy of investment; and out-of-state firms will be able to find the right mix of resources and expertise to merit locating a facility here.

NEWS FOCUS

Tom Moss

States Launch High-Tech Program To Bolster Industrial Economy

Many, such as Ohio, are establishing research centers keyed to universities strong in science and engineering, as U.S. drive to become more technologically competitive shifts to states

Wil Lepkowski, C&EN Washington

In each of the 50 states today, pots labeled High-Tech are boiling and steaming away, cooking up elixirs to cure the diseases the country fears most—technological obsolescence, loss of jobs, and sick economies.

From Alaska to Florida states are furiously designing policies specifically for developing, attracting, and holding onto companies with fresh ideas. The stake for the country is restoration of its leading place in the world's technological trade race.

"The initiative for change is no longer in Washington," declares Lewis M. Branscomb, chief scientist at IBM and former chairman of the National Science Board. "The states are becoming the pathfinders of new industrial policy," adds Arizona Gov. Bruce E. Babbitt, writing in the fall issue of the new quarterly, *Issues in Science and Technology*.

Celeste: sets of year 2000 strategies

State after state has established research parks keyed to universities strong in science and engineering, and is badgering those universities to gear up with new curricula and redirected R&D efforts. They are putting together new tax packages to help entrepreneurs and new firms conserve their scarce cash. And they are concocting other economic incentives in efforts to create that certain high-tech "climate"—one that will create, incubate, nourish, and attract companies working at the cutting edge of fast-changing fields. Those fields include, but are not limited to, computer technology, lasers, telecommunications, bioengineering, fiber optics, ceramics and composite materials, data processing, electronics, machinery, robotics, and areas of chemistry that apply everywhere across the high-tech world.

Indeed, if one were to take a lyrical view of the states and high tech, one would be tempted to use the word romance to describe the attraction. But former Ohio Congressman Robert N. Shamansky, who in his one term in Congress was a member of the House Science & Technology Committee, disagrees.

"Romance gives the trend a pejorative connotation," he says, with a wave toward Columbus' sprouting skyline. "If it's a romance, it's not a romance unfounded." Shamansky currently serves as chairman of a technology advisory board to Ohio Gov. Richard F. Celeste.

Under Celeste, Ohio is developing sets of "year 2000" strategies covering the labor force, Ohio's natural resources, its bureaucracy, and an ambitious new venture called the Thomas Alva Edison Partnership, a $32 million effort to corral business, academia, and state government for building a solid high-tech infrastructure through Ohio's economy.

The Edison Partnership consists of six state-industry-funded advanced technology centers in selected fields, a program of research grants to universities with promising fields of applied science, and development of a university-based technical information system that in intent will alert industry to promising findings in new fields.

It is in the old-line industrial states like Ohio where the promise of high tech will be tested. These states—Pennsylvania, Michigan, New York, New Jersey, and

Many locations vie for high-technology industries

The number of new jobs created by high-technology industries over the next 10 years probably will account for only a small fraction of total employment growth in the U.S. In many states and municipalities, nonetheless, high tech is being hailed as the key to economic revitalization. For one thing, those jobs that are created could have a significant economic impact in individual locations. And high technology has taken on a talismanic value for many state and municipal officials. Nearly everyone, it seems, would like to see the magic of Silicon Valley recreated in his or her home town. As a result, there is hardly a state in the nation that is not making some effort to attract high-tech research and industry.

The attractions vary, but the chief components are the accessibility of sophisticated academic cooperation, government financial inducements, and—to a lesser extent—quality of life. Local commercial development teams, naturally enough, tend to emphasize those aspects in which they compare favorably with the competition. They especially stress, when possible, the existence of an established R&D community—as proof of the viability of high tech in that location and as token of a basis for R&D interaction.

New Jersey, for instance, widely thought of as a smokestack state, likes to point out that high-tech industries accounted for 10% of its private sector employment in 1983. Commissioner Borden R. Putnam of the state's Department of Commerce & Economic Development notes that New Jersey has both a large number of educational institutions conducting applied research in ceramics, microbiology, waste management, fusion energy, and other areas, and the research centers of numerous corporations conducting applied research in the chemical, pharmaceutical, and electronics fields. These include Bell Laboratories, Allied, American Cyanamid, Merck, Schering-Plough, Hoffmann-La Roche, Squibb, Ciba-Geigy, Johnson & Johnson, and Du Pont.

To bolster this high-tech foundation, New Jersey's legislature has placed a $90 million high-technology bond issue on this November's ballot. Voters will be asked to approve a package that would provide $42 million for four advanced technology centers at the state's universities and colleges—$20 million for biotechnology, $9 million for industrial ceramics, $7 million for toxic waste management, and $6 million for food science. In addition, the bond issue would provide $15 million to establish a research center to study polymer processing and related topics, $23 million to build and improve undergraduate technical and engineering facilities for high-tech job training programs, and $10 million to be allotted by the State Board of Higher Education for capital construction projects related to high-tech training.

In Syracuse, N.Y., the city chamber

Indiana—are the country's industrial heartland. Unemployment is higher than anywhere else in the country. They are the regions most in need of renewal. And they know that, since their problems are acute, they must out-innovate the more geographically alluring Sunbelt states.

Despite its 9% unemployment rate, Ohio remains a powerhouse. It is headquarters for 25 of the Fortune 500 companies, more than any other state except New York and California. It is a formidable farm state, ranking eighth in farm production, a state rich in water resources, a top data processing center, and a state with such a high concentration of polymer scientists that Celeste has hopes of creating in the Akron-Cleveland corridor a "Polymer Valley." All that despite complaints of its entrepreneurs that Ohio lacks the venture capital and general climate needed to attract and keep people with new ideas.

"It's easy to go downtown to the banks and get millions of dollars worth of loans for a real estate venture," says one Ohio student of entrepreneurship, speaking only for background. "But for an inventor to get that $50,000 startup capital is another story. There's a ton of money around Ohio, but not a lot of it is available as seed, startup, or venture capital. I just don't know where you'd go for true startup money." One of the problems he sees is that the banks usually assign junior loan officers to handle the loan applications from entrepreneurs. Lacking the technical expertise and insight, the officers turn the loans down cold.

And Columbus' critics like to point to the saga of Dynamic Telecom Systems, a maker of an innovative computer that allowed one long distance telephone system to switch easily into another. DTS was born and nurtured in Columbus but, needing cash, it sold 51% of its equity to a Texas company. In a few months, the whole operation was moved to Dallas. "There wasn't a venture capitalist in Columbus interested in high technology," laments its former president John D. Ridihalgh in a May interview with the *Columbus Dispatch*.

Ohio watchers say the state has a way to go before it captures national attention as a high-tech mecca. Under Republican Gov. James A. Rhodes, who ran the state in split double terms of eight years each, Ohio acquired the reputation of a state that pirated others for new industry. "Rhodes' Raiders" converged on other states for more or less traditional industries such as the General Motors auto assembly plant at Lordstown and an Anheuser-Busch beer plant near Columbus, while ignoring such basic factors as secondary and higher education and a financial structure willing to take risks on entrepreneurial ventures.

So while other states were anticipating the revolutions in computers, communications, robotics, and biotechnology, Ohio went its own way, almost oblivious to the changes around it. There were exceptions. Columbus did become an innovative information communications center. Rhodes did lure Honda Motor of Japan to locate a motorcycle plant in Marysville

of commerce is in the midst of a four-year economic development plan that hopes to attract "targeted industries"—biotechnology, production technology, information processing, and water-intensive industries—to the area. For financial inducements, municipal boosters have to rely on the state of New York's package of tax breaks and other incentives, attractions offered by many other state governments. So the city is leaning heavily on a public relations campaign that emphasizes the area's existing high-tech base—Bristol Laboratories, currently carrying out research in applied molecular genetics and cancer chemotherapy; Borden, engaged in food technology R&D; Agway's Farm Research Center; and others—and a high standard of living.

In the South, Birmingham, Ala., is trying to attract biotechnology and biomedical firms. The University of Alabama, Birmingham, is building a $3 million biotechnology complex as an "incubator" for new enterprises. When completed in early 1986, the facility is expected to house up to 20 new biotechnology companies at a time. Emphasized here is the opportunity for very close interaction with the university. The institution runs a Center for Industrial Applied Research that serves as a conduit between the university and business. The program already has borne fruit: This spring the school's department of biomedical engineering signed a three-year contract with a developer of biomedical processing equipment. The firm gets lab space and research expertise from the university; the university gets an equity position in the firm. And town boosters say that the university's biology research and nearby Southern Research Institute make up a large market in themselves for many biomedical products.

All across the country, states and municipalities are parading their charms like so many entrants in a beauty contest. It seems more than likely, however, that only so many can be finalists. The Office of Technology Assessment, for example, in a July report on technology, innovation, and regional economic development, noted that for most communities, the greatest opportunities may lie in encouraging business development and technological innovation from within rather than in trying to attract high-tech businesses from other regions.

The public is not always so anxious about efforts to build up high-tech industry as government officials and chamber of commerce members may be. In Rhode Island this spring, voters resoundingly rejected the "Greenhouse Compact," a multimillion-dollar bond issue proposal that would have helped finance high-tech business ventures. And now comes word from Silicon Valley itself, the paradigm of what high tech can do for a local economy, that toxic electronic chemical wastes are tainting water supplies.

David Webber, New York

(while at about the same time 1600 jobs were lost when Toledo's glass industry was folding).

The state's vocational schools were hopelessly out of date, with no working relationships between the schools and the regional employers, its universities stayed aloof from the interests of industry, and in Columbus, Ohio State University and the internationally eminent Battelle Memorial Institute behaved as though neither institution was relevant to each other's interests. Meanwhile, Ohio's industrial economy fell into disrepair.

"For most of the past decade," says Celeste, "our state wandered around looking to the past for its inspiration and hope, not recognizing that in many respects our economy had changed. The question is, How do we deal today with global competition and technological change? What kind of institutions, what kind of tools do we have to be in a position to deal with that?"

One of the first things Celeste did when he came to office in 1982 was to hire an old friend, Alfred Dietzel, as his development director. Dietzel had been the strategic planner for the Columbus Chamber of Commerce and had extensive experience in helping communities develop long-range perspectives on their growth. He gave Dietzel the assignment to develop the outlines of a plan for Ohio and sent him on the road.

Dietzel worked fast. He knew high tech was the wave of the future, knew what Ohio basically had—enormous natural wealth, a salt-of-the-earth workforce, a vigorous farm economy—and he knew, therefore, that the base for growth was already there. The trouble was that the state was saddled with old ideas and competing bureaucracies in the capital. As he tells it, "We had to develop a strategic plan the private sector could feel it owned." He also had nearby a young man named Steven H. Holtzman who then headed the Ohio Development Financing Commission. Both of them went to different parts of the country examining the most successful programs of industrial development.

Dietzel says he learned five things. One, manufacturing had to be the centerpiece of any revival in Ohio. Two, business would expand or locate on a set of standard criteria such as the cost of energy, transportation, accessibility to markets and raw materials, the quality of life, the cost of living, and the cost of labor. Far down the list was taxes, once a prime inducement for bringing in new plants.

Three, he concluded that job growth came primarily from the growth of small business. That had to be a centerpiece, too. Four, the climate for entrepreneurship had to be set sizzling. And five, "Ohio's future depended on the ability of the universities and industry to get together."

"Most of all," says Dietzel, "we had to assume we were in a world economy and we needed to be competitive in the aggregate."

That may be today's standard formula, but Ohio had to discover it, then harness the state's private sector to work it all out. Next Dietzel and Holtzman

examined the high-tech programs in six advanced states: New York, Pennsylvania, Indiana, Connecticut, Massachusetts, and California. They also observed how one well-thought-out plan for Rhode Island failed for lack of citizen participation. The voters, distrustful of a team of planners dictating policies from the state capital with no input, simply turned it down.

"I learned," he says, "that for a strategic plan to work, the people affected by it have to be included in the planning process."

Holtzman then set to work devising the Edison Partnership. Then, tiring of the Ohio bureaucratic life, he moved to Cleveland to set up with some partners Technical Management Inc., a firm that will help university entrepreneurs establish new advanced technology businesses.

Meanwhile, Celeste ran all over the state promoting the new thrust, and earlier this month announced with the Midwest governors formation of a regionwide Great Lakes Commission on the Machine Tool Industry, a mainstay industry of the region.

And planning means a lot of things. High tech is part of the larger Ohio picture. Dietzel's development office is responsible for all aspects of economic growth in Ohio, like travel and tourism, block grants, assistance for small business, community development programs, housing assistance, and all are stories in themselves. But the key was still modernization of technology and attitudes, plus the attempt by Celeste to pull together in "Cabinet clusters" his departments so that they all think the same way: in terms of cooperation. Observers believe that some, like the jealously guarded and in many ways archaic Department of Employment & Training, will be impossible to harness.

"Celeste is putting a lot of attention to technology," declares Robert Fawcett, vice president for research and development at B. F. Goodrich in Beckwith, near Akron. "I give him big credits for that. I don't think all the states can successfully do the same thing, but Ohio has a good base from which to do it. And the state needs it. It is an industrial state, and it's suffering severely because of changes in industry."

And the Edison Partnership is, to Celeste, the key to that future. It consists of a program of research grants to universities in the state, and another program, just starting, of establishing in every major university a group of technology transfer experts trained to spot ideas that industries can use. Battelle, Control Data Corp., and Structural Dynamics Research Corp. of Cincinnati have been contracted to get these activities started.

But its centerpiece is six advanced technology centers running in a band from Cleveland-Akron in the northeast, through Columbus in the center, and the Cincinnati-Dayton area in the southwest, with a spur off to the southeast in Athens, site of Ohio University. Selecting the centers involved a competitive process, and the finalists were selected by a group of advisers located outside the state to ensure that the losers couldn't claim politics were at work.

"We took the lead from the regions," says Sandra

Ohio rates high in bank assets, corporate headquarters, but low in business climate

Category	Ohio ranking	Top state	Bottom state	Source
Manufacturing climate	46	Florida	Michigan	Grant & Co.
Corporate headquarters (38)	4	New York	Several with 0	Fortune 500 data
Bank assets	6	New York	Delaware	*Business Week*
Small business climate	29	Texas	South Carolina	*Inc.* magazine
Number of fast-growing small businesses	16	California	Several with 0	*Inc.* magazine
Number of business failures (660)	9	California	Vermont	Dun & Bradstreet
Average hourly manufacturing wage	4	Alaska	Rhode Island	Bureau of Labor Statistics
Violent crime index	27	Florida	South Dakota	Federal Bureau of Investigation
Stress index	21	Nevada (most stress)	Nebraska	U of New Hampshire
Per capita alcohol consumption	39	Nevada	Arkansas, West Virginia	Rutgers U
Per capita library book circulation	5	Iowa	Oklahoma	American Library Association
Per capita annual income	26	Alaska	West Virginia	Commerce Department
Jobless rate, 1983	8	West Virginia	Virginia	Bureau of Labor Statistics
Environmental effort	18	Minnesota	Alaska	Conservation Foundation
Annual pupil expenditure	25	Alaska	Arkansas	U.S. Education Department
Number of scientists and engineers	5 (156,000)	California	Maine	National Science Foundation
Number of small business innovation research awards	5	California	Nine with 0	Small Business High Tech Institute
% high-tech labor force	8 (4.2%)	California	Six at 0.1%	Small Business High Tech Institute
Federally supported university R&D (fiscal 1982)	10	California	Maine	National Science Foundation

Note: Above nontechnical data are assembled in June 30, 1984, issue of *National Journal*.

M. Slezak, acting director of the Edison program. "A lot of them came to us with their greatest strengths." She says 26 applications were received in all.

Each center will have as its focus university R&D talents but will be incorporated separately and in most cases be located off-campus. The board membership will be dominated by the industrial sponsors who will see to it that after a few years the centers no longer need state funding. The whole idea will be to develop areas of knowledge applicable to "generic" needs of the sponsoring industries, and any new ones that spring up as a result of the activities of the centers. One of the essential functions of the centers will be vigorous outreach and marketing programs to ensure that the findings generated at each center are transferred as fast as possible to practical uses. On commercialization, some of the royalties will go back to the state.

A scan of the centers reveals that Ohio is shunning the scattershot approach to technical planning. Rather than begin with a selection of glamorous high-tech fields with little indigenous base for their development, the state decided to select fields in which Ohio was already strong: advanced manufacturing systems at Case Western Reserve (Cleveland) and the University of Cincinnati, welding at Ohio State, information technologies in the Columbus area, and polymers in the Cleveland-Akron area.

The weakest center appears to be the Recombinant Animal Biotechnology Center at Ohio University in Athens, hardly considered a region with a strong bioengineering entrepreneurship. Still, the university boasts of a strong program of recombinant animal DNA research in its zoology department. Ohio University is not a land-grant school and thus lacks the strong infrastructure in the agricultural sciences that land-grant Ohio State University has. So there is always the threat that the program could be moved to OSU, which with Case Western Reserve is a participating institution.

"We're all going up the learning curve on this one, with respect to working with industry," says Ohio State assistant engineering dean Robert Redmond. "The things new here are the massive state funding to foster more formal arrangements with industry, plus bringing in organizations that have not had classic ties, plus seeing what can be done to make these entities interact. Without state initiative, it probably wouldn't have happened. And the question will be whether the players will be able to pick up the ball and run with it."

The center of most interest to the chemical community is Edison Polymer Innovation Corp., which received $4.1 million in state funds and will be operated jointly by the University of Akron and Case Western Reserve. The polymer center, according to Lynn G. Johnson, provost of Akron University, will be naming its director later in September. Akron is, of course, the historical capital of the rubber industry. Although most rubber manufacturing has left Ohio for points south and abroad, the area remains the corporate and R&D headquarters for the industry. So what the Akron-Cleveland area has, its proponents say, is the largest concentration of polymer R&D know-how in the world.

So the center's backers see it as the focus of what will eventually become "Polymer Valley," making northeast Ohio the "polymer capital of the world," according to the center's strategic business plan.

Its industrial sponsors include Dow Chemical, Ferro Corp., Firestone Tire & Rubber, B. F. Goodrich, Goodyear Tire & Rubber, Monsanto, Sherwin Williams, Standard Oil (Ohio), and TRW. The lines of research expected to be pursued are polymer processing, synthesis of special macromolecules, mechanics of fabricated polymer parts, lightweight composites, polymer blends and alloys, membranes and coatings, polymers in medical applications, and polymeric electronic and optical materials. Its staff will be a mixture of industrial and academic researchers, plus scientists employed by the center itself.

Right now, the center looks like an organizational and geographical jabberwocky. Indeed its founders wondered whether it could even get off the ground conceptually. Practically the only thing the University of Akron and Case Western Reserve have in common is the presence of students, faculty, and buildings, besides their individual strengths in polymer science and engineering. Akron is a state school; Case Western Reserve is private. They have separate patent policies that must be altered so that the center operates under one. And as polymer research centers, they have always been rivals, competing for the same federal money. Researchers could have some trouble knowing at any given moment for whom they work, with state, federal, institutional, and private money all funneling in to support the research and programs.

"One of the things that make the operation of the center sticky," says Johnson, "is that there will be several funding channels that must be kept track of." But this is typical of university-industry cooperative ventures, so he sees no real trouble ahead.

"The really interesting thing about this venture is the central assumption that by bringing the universities and industries together in a higher level of cooperation, something qualitatively different may happen with respect to the economy. And it is difficult to specify what that may be. I'm a student of higher education, so I am fascinated with these connections."

Although all of the other centers will be housed in a single building off the campus—they are, after all, separate corporations—the polymer center will be kept separate only by accounting procedures. The laboratory work, in basic and applied polymer science and technology, will take place in the university laboratories. The director, however, will be situated in separate headquarters. In a sense, he or she will direct the allocation of monies and the transfer of polymer knowledge all over the state. (Ohio has little interest in exporting knowledge; it already has exported hundreds of thousands of jobs.)

Goodrich's Fawcett volunteered to be the industrial liaison for the center and he's fascinated with the experiment, too. "A very important part of the whole thing is taking two polymer centers that already exist

and getting them to operate in a fashion that will give you a synergistic effect so that we have in northeast Ohio a world class polymer center," he says.

But there are difficulties, he admits. "The two schools want to operate on their own patent policies," he says, "and that's going to have to be resolved. A company has the tendency to work with the school giving it the best break. The center will have to have its own patent policy irrespective of what individual school it operates under. But as structured today, the policy isn't there."

Fawcett doesn't believe the collaborating corporations will have any problems allocating the knowledge produced at the center. "While we're competitive," he says, "we know each other quite well. There's a great deal of cooperation in the sense of creating community support. I don't think that in these areas of research, intercompany competition gets in the way." He believes the companies can come to an agreement over which lines of research one or another company wants to pursue on its own.

Akron deputy mayor Michael Hudkins is confident that Akron can make it back on the strength of Polymer Valley. "Akron may have lost its rubber manufacturing activities, but it's still a high-tech place," Hudkins says. "The brains are still here; $420 million was spent on R&D last year. But we do have an image problem to overcome, since high tech is usually identified with electronics."

But for all this, it seems that if Ohio is going to come back to a world whose symbol is the chip rather than the gear, Ohio still will have the human resource problems that the state is not yet showing signs of truly facing.

"Even when high tech is very broadly defined," says a recent study on it by the Bureau of Labor Statistics, "it has provided and is expected to provide a relatively small proportion of employment. Thus, for the foreseeable future, the bulk of employment expansion will take place in nonhigh-tech fields."

As for Al Dietzel, the perpetual optimist, the future couldn't look brighter. Everywhere in the state he goes, he says, he urges people to make strategic plans for the future of their cities and counties—to list their advantages and take steps to make them more attractive to outsiders.

Ohio still has a way to go. Unemployment is still high. Jobs are still being lost. In Columbus early this month, R. G. Barry Inc. announced it would close its slipper-making plant and move its operations to Texas. About 270 jobs were lost. Bucolic Portsmouth, set on the Ohio River south of Columbus, lost almost 8000 jobs since the late 1970s and hangs by a thread in the form of a Department of Energy uranium enrichment plant, which employs 3000. And only last May Diamond Shamrock moved its corporate headquarters from Cleveland to Dallas.

Dietzel quickly admits that manufacturing jobs will have to go. But he sticks to the belief that more jobs will be created in the process, with few of them boring. What will happen, he believes, is that high tech is going to spark thousands of small businesses, from research to services. "Take Whirlpool here in Columbus," he says. "They raised their productivity five- to sixfold during the past 10 years. And what they've done in the process is hire more of their legal, accounting, and data processing services from the outside. It's the same for company after company."

Battelle's Charles W. Minshall, economic geographer who helped develop New York state's high-tech program and is working on plans for the state of Florida and the city of Indianapolis, says he believes people are going to live in the year 2000 much like they live in 1984. There will be the technology "ins" as well as the technology "outs." Not a lot of attention is being paid to the outs in Ohio these days, except in the conventional terminology of retraining and welfare. The hope is that technology will deliver a new Ohio and with patience the future will work itself out. A draft of Celeste's strategic plan for human resources mentions as a goal economic independence for Ohioans. But one can hardly imagine how high tech is going to bring about independence to the 1.5 million to 2 million poor and elderly Ohio projects for the year 2000.

Celeste's strategic plan shows no sense of problems that might lie ahead as a result of the high-tech revolution, or, say, of the impact of another energy crisis on the state and its people. It fails to integrate Ohio's agricultural resources with quality of life issues that could emerge in the 1990s and beyond. But to be fair, it does speak of energy conservation and the diversification of Ohio's agriculture.

But Celeste does appear to have an awareness of the possibilities that "low technology" married to high technology could have for Ohioans. He tells C&EN, "There is a dimension of concern for the opportunities afforded by appropriate technology. One is the application of groundwater to heating homes and businesses. Ohio is the headquarters of the National Well Water Association and there's a lot of interest in that. And we have in Ohio a lot of people working on raw material for solar energy application. Another dimension of interest is to work on an electronic network for distributing information on technology transfer."

Still, it may well be that two societies will be emerging in Ohio—a technocratic elite, deft, wealthy, plugged into the monetary flow that nourishes technology and its underpinnings, and that segment caught in the undertow.

Michael Goldhaber, director of the Technology & Democracy Project for the Institute of Policy Studies, sees things exactly in that light and describes a scenario Celeste would hope to avoid. Writes Goldhaber: "If job-replacing technology is increasingly widely adopted, rising unemployment will follow. . . . A small but growing segment of society will continue not only to do well, but to be more firmly than ever in the saddle in terms of influencing subsequent changes. This pattern will continue with unemployment growing with each cycle." Goldhaber makes a pitch for development of community life, which Ohio appears to have in abundance, rather than "efficiency for its own sake."

Dietzel (left): competitive in the aggregate. Johnson (center): problem is several funding channels. Strauch: understand external world's impact on Ohio

Patricia G. Strauch, president of a Cleveland firm called Perspective Decision Models, believes the Ohio planning process needs an outlook even more broad than the strategic planning documents. "There has to be an understanding of the external world and its impact on Ohio. Until you establish that perspective, you can't say that throwing money at high tech will secure the future. Ohio has water, farmland, tremendous natural resources, things to look upon as assets compared with competitor states like Colorado or Arizona. There's no real understanding of what the state has that's unique," she says.

Strauch is in a rarefied field known as global modeling and currently is producing for the Joint Chiefs of Staff at the Pentagon a computerized system that assesses world trends in such areas as national politics and policies, finance, natural resources, energy, and industrialization. The Joint Chiefs' hope is that such a model will enable them to view issues of national security more comprehensively.

In any case, her comments are in stark contrast to the expressions of optimism that come forth from Columbus. "Nothing's being done that is anything different from anything the other states are doing. And that's the real tragedy. If you look around the world, you see service industries made up of only clerklike workers. And yet, the corporations making up Cleveland Tomorrow have no greater vision than their individual strategic plans. I talked to executives from Republic Steel. They insisted that steel always has recovered and would recover in the future. Clevelanders feel they live in a little town and see the outside world as much too complicated. It's a city with tons and tons of money and yet can't support itself."

Thomas Closser, director of the multicounty Buckeye Hills/Hocking Valley development district based in economically ailing Marietta, says: "I have my doubts over whether the high-tech revolution is ever going to have much of an effect here. The development of the Appalachian region is something that's not going to happen very fast. Ohio has no setup like the one in North Carolina, where money was put into high-tech development for a number of years.

"Ohio University has an innovation incubator center, but I don't see that helping southeast Ohio very much. What we're trying to do is work more with existing businesses and get new ones established—small ones employing 25 to 200 people. We've never had much cohesive effort put together here. We have to diversify the area in one fashion or another. The area is not a hell of a lot better off than it was when Reagan took office."

Celeste appears to perceive the subtleties in high tech and Ohio's future, however. He says the key to Ohio's future is in its community life. "One of the themes to our development promotion," he says, "is 'Ohio—the Heart of It All.' Part of what we have to focus on is our communities. Our work has to be set in the longer-range context. I don't see any big political gains out of this. The program is not to gain 10 jobs next week, but to protect 5000 over the next four to five years, and bring 5000 more in."

So one hopes. But what one does know is that the high-tech revolution presents a paradox. In the future of community life, the future of work, the future of governance when a technological elite controls the flow of finance and knowledge, there are questions with no purely technological answers.

The high-tech revolution is happening, and by all conventional economic reasoning it must. No one really has the answers to the displacements ahead. And all one can express is that those who direct the process in its investment and public policies be clear about the things they need to know more about. □